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REPORT

ON THE

EASIBILITY OF THE DEVELOPMENT OF HYDRO ELECTRIC POWER

FROM THE

MISSOURI RIVER

IN THE

STATE OF SOUTH DAKOTA

BY

DANIEL W. MEAD
CHARLES V. SEASTONE

CONSULTING ENGINEERS

MADISON, WISCONSIN

APRIL 1920

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Page 4 9 lines from top, "those" should read "that".
Page 8 16 lines from top, "con" should read "can".
Page 10 3 lines from bottom, "are" should read "is".
Page 10 6 and 7 lines from bottom, "advantageously" should read "advantageously".
Page 14 7 lines from top, after "to" insert "be".
Page 19 7 lines from top, "have" should read "has".
Page 27 10 lines from bottom, "esimate" should read "estimate".
Page 31 10 lines from top, "effect" should read "affect".
Page 33 8 lines from top, "contruction" should read "construction".
Page 34 10 lines from top, "are" should read "is".
Page 39 7 lines from top, "on" should read "of".
Page 39 8 lines from top and 25 lines from top, "%" should read "%".
Page 42 15 lines from bottom, "conection" should read "connection".
Page 43 Table 8, No. 24, Load conditions, "22 ov" should read "220 volts".
Page 46 Table 10, year 1929, profit, "\$446000" should read "\$466000".
Page 49 20 lines from bottom, "was" should read "were".
Page 65 17 lines from bottom, "portion" should read "portions".
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Page 75 14 lines from top, "were" should read "was".
Page 78 1 line from top, "begin" should read "began".
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Page 93 14 lines from bottom, "fete" should read "feet".
Page 104 Table 19, first line Mobridge Estimated Cost, "\$735,000" should read "\$735,500".
Page 108 13 lines from bottom, after "fact" insert "that".
Page 108 Table 20, sixth line, Sioux Falls Distance, "27" should read "37".
Page 113 20 lines from bottom, "give" should read "gives".
Page 114 15 lines from bottom, "number" should read "numbers".
Page 116 3 lines from top, "initaly" should read "initially".

BY

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BY

DANIEL W. M
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APRIL 1920

Date Due

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PREPARED UNDER THE DIRECTION OF
THE HYDRO-ELECTRIC COMMISSION
OF THE
STATE OF SOUTH DAKOTA

BLUED PRINTING CO., MADISON, WIS.

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LETTER OF TRANSMITTAL

TO THE HONORABLE HYDRO-ELECTRIC COMMISSION
OF THE STATE OF SOUTH DAKOTA,
Pierre, South Dakota.

GENTLEMEN: In accordance with your instructions, we have investigated the power possibilities of the Missouri River in the State of South Dakota and the various sites at which hydro-electric power might safely and profitably be developed.

We have also investigated the probable cost of developing the most promising power sites and the cost of the transmission system necessary to supply the power to the present market.

Our investigations have included a census of the present market where hydro-electric power might be utilized to advantage, the present cost of power generated from fuel at such market, and the prices at which hydro-electric power might profitably be sold.

We have also considered the feasibility of the project both from the standpoints of private investment and of development by the state. Our findings are given in the attached report in which a general discussion of the project is included in the main report and a more detailed discussion of the more technical matters are embodied in the appendices thereto.

We have summarized the main points of our findings in the following conclusions.

1. That physical conditions are favorable to the safe development of hydro-electric power plants at various sites on the Missouri River in South Dakota.

2. That the best site for immediate development, all things considered, is about four miles above the city of Mobridge, where a plant may safely be constructed with a thirty foot head at less first cost than at any other point on the Missouri River in South Dakota.

3. That it is entirely impracticable at the present time, on account of the great cost involved, to construct a transmission system that will reach all the cities, and villages of the state but that such lines must be limited, for the present, to the more thickly populated eastern part of the state.

4. That if this project is immediately undertaken it could probably be completed in 1925.

5. That the cost of the development of a water power plant with a thirty foot head at Mobridge, on the basis of present prices, and exclusive of the transmission system is estimated at \$9,103,000.

Power from the Missouri River in South Dakota.

6. That the cost of the most extended transmission system that appears expedient at this time is estimated at \$7,044,000.

7. That the total cost of construction of the entire installation is estimated at \$16,147,000.

8. That if various communities can be induced to construct the secondary transmission lines and substations at their own expense the total cost to the State might be reduced to approximately \$13,900,000.

9. That the available market seemed to offer, in 1919, a load of about 30,000,000 kilowatt hours per annum now developed from fuel and for which hydro-electric power might profitably be substituted.

10. That the market may be expected through the encouragement afforded by cheap power to increase at a rate of about ten per cent per annum.

11. That the cost of power from fuel at the various power plants of the state varies from 1.7 cents to ten cents per kilowatt hour, based on entire station charges, and from one cent to five cents per kilowatt hour, based on fuel costs only.

12. That the price at which power must be sold to power users to be attractive must be below station costs and in some cases must be as low as fuel costs.

13. That the unit cost at which power can be developed at the Mobridge site when the entire output amounting to 87,600,000 kilowatt hours per annum, is sold would be 1.60 cents per kilowatt hour with the full investment included and 1.34 cents per kilowatt hour if secondary transmission systems are furnished by customers.

14. That the average price at which power must probably be sold from the proposed hydro-electric plant would be about 1.87 cents per kilowatt hour with secondary transmission line furnished, or at 1.67 cents per hour if the customers furnish the secondary transmission systems. By such charges a profit above fixed and operating costs would be realized from which the original capital costs could be gradually retired, or a fund could be accumulated to provide for future hydro-electric developments.

15. That such prices could fairly and reasonably be increased with the gradual rise in fuel prices that is certain to occur.

16. That based on the prices suggested and the consequent returns from the market available in 1919, the income for the first five years would not be sufficient to pay interest and operating expenses but would necessitate deferring depreciation charges and the investment of a further sum of about \$1,500,000 to meet temporarily unearned interest during the period of the development of the market.

17. That when the market increases to about 53,000,000 kilowatt hours per annum, the income from the plant would thereafter pay interest and operating expense and with the further increase in consumption of current would gradually retire the development fund, establish a depreciation fund, and begin to retire the capital costs.

18. That if the market should develop to a capacity of about 53,000,000 kilowatt hours per annum, by the time the proposed hydro-electric plant and transmission system are completed, the resulting income would be sufficient to provide for interest

and operation charges. No development fund would be necessary and with the further growth of the market a depreciation fund would accumulate and the plant would soon earn a sufficient sum to begin to retire the capital cost or to accumulate a fund for future developments.

19. That the period of development would, on the basis of a growth in the power market of ten per cent per annum, be about ten years on the basis of the 1919 market conditions, but would probably be shortened by the increased market which would obtain by the time the plant and transmission system are constructed.

20. That a slower growth would involve a greater development cost and a slower recovery. If stagnation in growth occurs through financial panics or from other causes, the loss from unearned interest would continue and failure to refund the capital cost might allow.

21. That if the market will warrant the investment, the plant at Mobridge might be developed to a forty foot head which would reduce the unit cost of current to 1.35 cents per kilowatt hour when the entire resulting output of 117,000,000 kilowatt hours per annum is marketed.

22. That such an increase in head in the Mobridge plant would add approximately \$2,300,000 to the cost of development.

23. That when the industrial development of the state utilizes the entire output of the proposed Mobridge hydro-electric plant a second plant at the Mulehead site should be constructed.

24. That the unit cost of current would decrease to about 1.2 cents per kilowatt hour when the entire output of both plants with thirty foot heads, amounting to approximately 200,000,000 kilowatt hours per annum, is sold.

25. That in view of the present high cost of development and the necessary length of transmission to reach the limited market, the cost of such developments would be too great and the returns to be expected too small to attract private capital.

26. That even under present conditions, if a rate of growth of the power market of 10% per year can be reasonably anticipated, the state can afford to undertake the development with every prospect of attaining adequate financial returns to maintain and ultimately to liquidate the investment.

27. That such results can only be attained by conservative financing, intelligent design, economic construction, scientific management and careful operation. These conditions can obtain only through honest and intelligent administration entirely free from political interference. Any departures from these principles would seriously affect the results shown and might involve the state in serious losses.

28. That the returns to the people and the state of South Dakota would consist:

In the development of manufacturing and industrial life;

In the betterment of living conditions and transportation facilities;

In the annual saving of great quantities of the exhaustible fuel resources of the state and the nation;

And in the general increase in prosperity and property values.

Power from the Missouri River in South Dakota.

29. That these desirable consequences will obtain as a result of the development of water power on the Missouri River, there can be no question, although the extent and rapidity with which they will be attained is necessarily uncertain.

30. That in our opinion the present costs of development are fully one-fourth above the costs which we believe will ultimately obtain when this country again reaches a sane and sound business basis. If such prices should be attained within a few years it would undoubtedly be advisable to defer the development to such time, for under such conditions the financial return from such a plant would be materially better than those shown in our report. When such a condition will obtain is a question which cannot be answered but it can hardly be expected in the immediate future.

31. That we have endeavored to fairly present all conditions of the problem and all of the risks involved. Whether or not, under the conditions which obtain, the state of South Dakota should undertake the hazards of the development and sale of hydro-electric power we do not feel called upon to answer. This is a question which involves many considerations besides those purely of business and engineering. They are such questions as must be answered by those who are directly responsible for the financial integrity and industrial development of the state of South Dakota.

In conclusion we desire to acknowledge the uniform courtesy and valuable advice of the members of your honorable Board. We wish especially to acknowledge the valuable assistance of Honorable Doane Robinson, Secretary of the Hydro-Electric Commission, to whose intelligent foresight, abounding faith and continuous efforts, the passage of the hydro-electric bill and this resulting report are most largely due. We also wish to express our appreciation of the information kindly furnished by the various owners and operators of the power plants of the State, and of the kind reception and courteous aid freely given by many citizens of the State.

Respectfully transmitted,

DANIEL W. MEAD,
CHARLES V. SEASTONE,
Consulting Engineers.

Madison, Wisconsin,
April 10, 1920.

LAWS DEFINING THE AUTHORITY FOR AND THE SCOPE OF THE INVESTIGATION

This investigation was undertaken in accordance with a statute of the State of South Dakota which is based upon the following amendment to Article 13 of the State Constitution, adopted by joint resolution by the Senate and House of Representatives and afterward approved by a vote of the electors of the State:

Section 10. The state may purchase, own, develop and operate plants for the development of power, upon streams of this state and at coal mines upon lands owned by the state and may transmit such power and supply the same to the people of the state. The state may pledge such plants and the accessories thereto to provide funds for such purchase and development any thing in this constitution to the contrary notwithstanding. The legislature by a two-thirds vote of the members elect to each house shall provide by law for carrying the provisions of this act into effect.

In accordance with the above constitutional provision, the Senate and House of Representatives passed the following statute creating The Hydro-Electric Commission and defining its powers and duties:

Section 1. The Hydro-Electric Commission is hereby created, to consist of the governor, the secretary of state, the chairman of the railway commission, the state engineer and the secretary of the department of history, each of whom shall serve without additional compensation, but whose actual, necessary expenses as such commissioners shall be paid. Said commission may employ necessary clerical assistants. The governor shall be chairman and the secretary of the department of history shall be the secretary of said commission. Said commission shall keep a complete account of all its transaction in substantial books of record.

Section 2. Said commission is hereby empowered to employ competent and experienced engineers, and to cause an engineering reconnaissance of the Missouri River in South Dakota to be made sufficient to determine the feasible power sites thereon, and to select therefrom the one most available for immediate development, having in view the volume of power, cost of development, convenience of transmission of electric current therefrom throughout the state, and the advantage to be derived from the use of the dam structure for bridge purposes; and shall cause a detailed survey of the location so chosen to be made, sufficient to determine the probable cost of such development, and the cost of efficient transmission by trunk lines, whence current may be distributed to every

Power from the Missouri River in South Dakota.

part of the state according to the most approved plans for such transmission; and the said commission is further empowered to employ consulting engineers of high character and proved ability to check the work of the engineers in charge.

Section 3. Said hydro-electric commission shall carefully investigate the probable market for electric current to be generated by such proposed power plant and make provisional contracts for the sale of such current upon the completion of such plant.

Section 4. The said commission is empowered to enter into tentative agreements with the United States for the grant of power privileges upon the Missouri River to the State of South Dakota, and for the co-operation of the United States in the survey and development of such power plant and incidental navigation locks.

Section 5. The said Hydro-Electric commission is instructed to make a report of all its doings, showing among other things the proposed point of development, the character and type of the construction proposed; the system of transmission proposed and the location of the trunk lines and necessary accessories to such development and transmission and the total estimated cost thereof, and the substance of any agreements entered into with the United States, which reports shall be published and be presented by the governor to the next general or special session of the legislature.

Section 6. There is hereby appropriated out of any money in the treasury, not otherwise appropriated, the sum of fifty thousand dollars, or so much thereof as may be necessary, to be paid upon the warrant of the state auditor issued against the vouchers of said Hydro-Electric commission, duly approved by the governor, for any expense necessarily incurred by said commission in carrying out the purposes of this act, which money, so appropriated, shall be available until used.

Section 7. Whereas this act is necessary for the immediate support of the state government and its existing institutions an emergency is hereby declared to exist and this act shall be in force and effect from and after its passage and approval.

PETER NORBECK,
Governor.

Approved February 26, 1919.

REPORT ON THE FEASIBILITY OF THE DEVELOPMENT OF HYDRO-ELECTRIC POWER FROM THE MISSOURI RIVER IN THE STATE OF SOUTH DAKOTA

The great Missouri River that flows across the entire State of South Dakota from its northern to its southern boundary for a distance of almost five hundred miles, has a total fall of over four hundred and fifty feet and affords a potential power of over four hundred thousand continuous horse power. Nearly one-half of this, which would be equivalent to a total of over one-half million horse power as power is ordinarily used by public and private power plants (with an average load factor of thirty-three per cent) may ultimately be developed to advantage for the benefit of the State and its citizens when and as it is found financially expedient to utilize this great natural resource.

CONDITIONS UNDER WHICH HYDRO-ELECTRIC DEVELOPMENTS BECOME FEASIBLE.

Potential water power is valueless at any time or place until it can be developed economically and profitably utilized. For such condition to obtain:

1. It must be practicable to develop hydro-electric power and transmit it to a market at a price sufficiently low to insure its use.
2. There must be a sufficient demand for power to warrant the construction of a water power plant and the transmission of the power to a market, or such market must be capable of early development.
3. The market must afford a price for power which will:
 - (a) either pay fixed charges on the investment and operating expenses, plus a sufficient profit to induce private capital to invest in the enterprise;
 - (b) or pay fixed charges and operating expenses plus a sinking fund which will ultimately retire the investment cost and result in such a growth of industries as will make it desirable for the State to undertake such development.

PRESENT DEVELOPMENT BY PRIVATE CAPITAL IMPRACTICABLE.

Private interests can be induced to undertake new water power developments only under circumstances where the cost of development will be so low and the price received for power will be so high that the investment will pay, above ordinary fixed charges and operating expenses, a surplus commensurate with the possible risk involved in the venture. Investors find safe and conservative investments at 6 per cent. in well matured bonds and can place money in preferred stocks at 7 per cent. and even at 7½ per cent. without any serious risk. The development of a state, the increase in general public prosperity, the improvement of living conditions, or the

saving of fuel afford to private companies no direct returns which can be transferred into dividends and satisfy stockholders. It is therefore impossible to interest private capital in a new water power development involving the uncertainties of construction and the development of a market unless there is a fair opportunity of earning approximately 15 percent. on the investment. *Under present conditions the development of water power on the Missouri River in the State of South Dakota cannot be accomplished at a sufficiently low price, and the market afforded by the scattered population of South Dakota is not sufficiently extensive or remunerative to make such a venture attractive to private capital, and it is believed that conditions sufficiently attractive to induce private investment in water power from the Missouri River in South Dakota will not obtain for many years to come.*

FEASIBILITY OF DEVELOPMENT BY THE STATE.

The people of South Dakota will naturally regard the development of water power within the State from a somewhat different point of view from that of private investors. Any project financed by the State and with the credit of the State behind it can secure money at a rate materially reduced below that possible for any private enterprise.

The State with its extensive resources and great credit is not obliged to look for immediate returns to satisfy the demands of numerous investors but can disregard taxes, depreciation and even a part of the interest for a term of years provided an ultimate return is assured which will properly provide for these elements and eventually retire the investment.

The reward of the people of the State for such a venture, beyond the bare return on the financial investment, would consist in the development of the manufacturing and material welfare of the state; in the general rise in property values and in the betterment of living conditions and transportation facilities which will result from abundant and cheap power. Such material betterment will result in an increase in population and taxable property and in an indirect return which is likely to be of great importance and value.

There is a further advantage in the development and utilization of water power which is not fully recognized by the public but which nevertheless is of vital importance to the future of the citizens of South Dakota and of the other states of the Union. At the present time thousands of tons of coal and thousands of barrels of fuel oil are annually used for generating power where water power might be substituted. The saving of these exhaustible fuel resources, which can never be restored, for the use of future generations, is an end most desirable to attain. On account of the short sighted policy of the Federal Government, and the unworkable laws which have been passed at Washington, practically no developments on the navigable water or on the streams within the public domain have been possible within the last ten years. A new law more liberal in character is now before congress which, if passed, will permit of such developments both by the state and by private interests. This is a most desirable end in view of the possible saving in fuels which would result. It is our belief that

the nation and the state should use every effort to conserve our exhaustible fuel resources and this aim is believed to be an important factor in the consideration of the development of water power on the Missouri River by the State of South Dakota.

As an example of the saving in fuel that might be effected by the development and utilization of 500,000 commercial horse power on the Missouri River it may be stated that on the basis of 3 pounds of coal per horse power hour, the total fuel represented by this power would be over 2,000,000 tons of coal per annum.

COMPARISON OF THE PRACTICABLE BASES OF STATE AND PRIVATE DEVELOPMENTS.

The following table shows the percentage of returns on the capital cost of an investment believed necessary to induce private capital to construct water powers, compared with that which may be regarded, together with other indirect returns, as fairly satisfactory to the State:

	PRIVATE INVESTORS	STATE
Interest	7 percent.	5 percent.
Operation	1	1
Depreciation	3	3
Taxes	1	0
Profit or Sinking Fund.....	8	1
	—	—
	20 percent.	10 percent.

From the above table it is apparent that the State may be able to finance a hydro-electric development on the basis of a market which would return only about one-half the gross earnings which would be necessary to attract private capital.

It is believed that the above percentages fairly represent the relation of possible State development of water power on the Missouri River. It is believed that private capital could not be induced to make this investment unless the prospects were good for the returns indicated, and while the percentage shown for the State investment may not be sufficient to make the investment attractive as an investment, the resulting development of the State will offer an inducement more potent than immediate financial returns. Furthermore, it is probable that a market which would, in the course of the next two decades, afford such returns as would be demanded by a private enterprise is not to be expected. On the other hand, it is probable that by judicious management the State can secure better results than indicated above. *It is therefore evident that any development at this time or in the immediate future, must be undertaken by the State or that the project of developing the water power on the Missouri River in South Dakota must be abandoned for an indefinite period.*

STATE OWNERSHIP AND OPERATION OF PUBLIC UTILITIES.

Ordinarily it is believed not to be expedient or desirable for a nation, state, or any of its political subdivisions to undertake developments which can be successfully financed by private capital. Public ownership lacks the incentive, the initiative, and

the sense of personal responsibility necessary to develop and especially to operate great enterprises with the maximum success. Political influence and failure to secure the best economic and technical management are apt to seriously affect such enterprises sooner or later, and the direct profit to the state, which may seem apparent from the figures presented above, is likely to prove falacious in the long run. Yet there may be a time with every nation and every state when the needs of development seem to warrant a departure from these principles. Bonuses in the form of the loan of national credits and land grants were in the early days of our nation frequently granted by the federal government to encourage the development of the West; and almost universally and in spite of extravagance and occasional dishonesty, the resulting growth and prosperity of the communities benefitted by such developments have more than warranted the encouragement extended.

If therefore it appears that the State of South Dakota, by a judicious investment, honestly and intelligently made and administered, can develop a system of water powers on the Missouri River which, by furnishing cheap power to the industries and inhabitants of the State, will build up the State, develop its resources, increase its property values and its prosperity, add to the comfort and convenience of its citizens, effect a great saving in the exhaustible fuel resources of the state and the nation, and at the same time earn a sufficient income to pay interest, depreciation and operating expenses, and ultimately return the invested capital to the State, the project is at least worthy of the careful consideration of the State Legislature and of the citizens of South Dakota.

THE PROBLEM.

The problem to be considered in this report is then the practicability of the selection of a power site on the Missouri River at which power can be developed at such a cost that it can be transmitted and sold in a market existing or capable of early development.

The studies upon which this report is based include primarily studies of the market conditions, of the flow of the Missouri River, of the available heads, of the physical condition at the principal power sites, of tentative plans for such developments, of the cost of their installation, of a practicable transmission system and its cost and of the practicability of the entire project.

THE IMMEDIATE MARKET.

From a study of the market conditions, made to determine the amount of power used in the State and more especially to determine what power might be advantageously replaced by hydro-electric power from a State development, it is evident that only that part of the State east of the Missouri River can practically be considered at this time. The accompanying map (Figure 1) shows the locations of cities and towns the present population of which are over 300, and conveys a relative idea of their populations by the size of the circles. The map clearly presents the problem of market and transmission and shows, in connection with the estimates of the cost of trans-

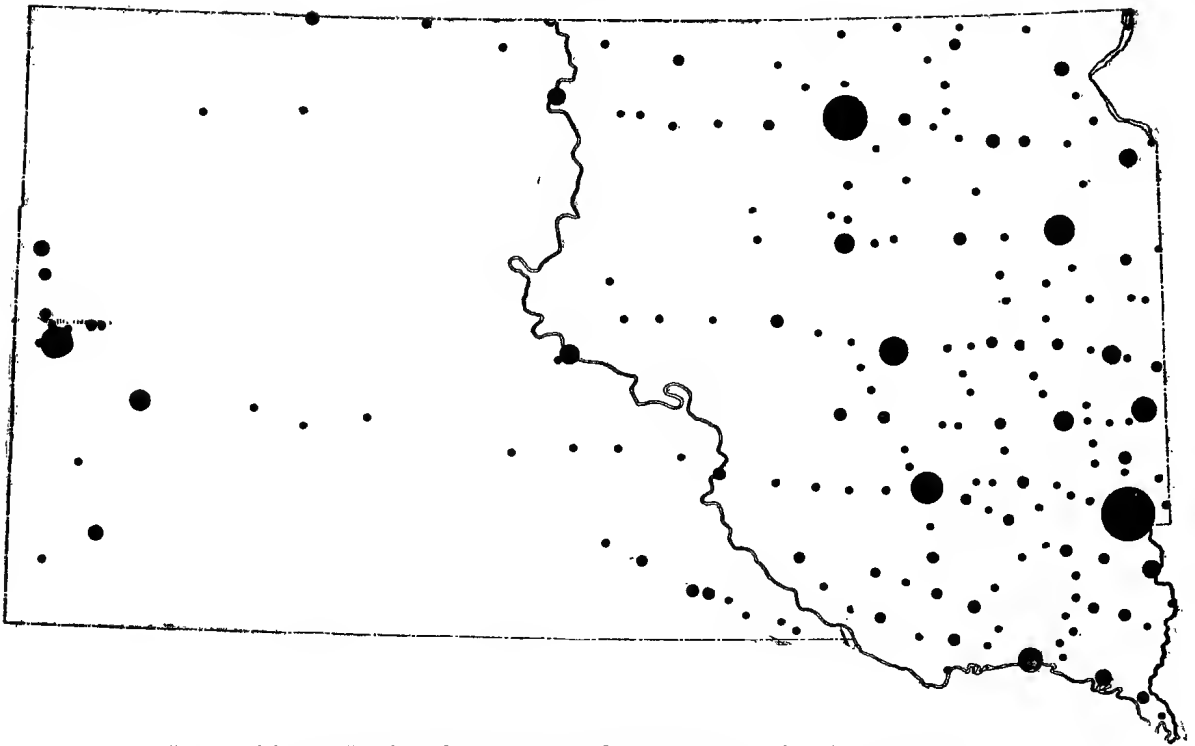


FIGURE 1. Communities in South Dakota of more than 300 Population (relative population indicated by size of circles).

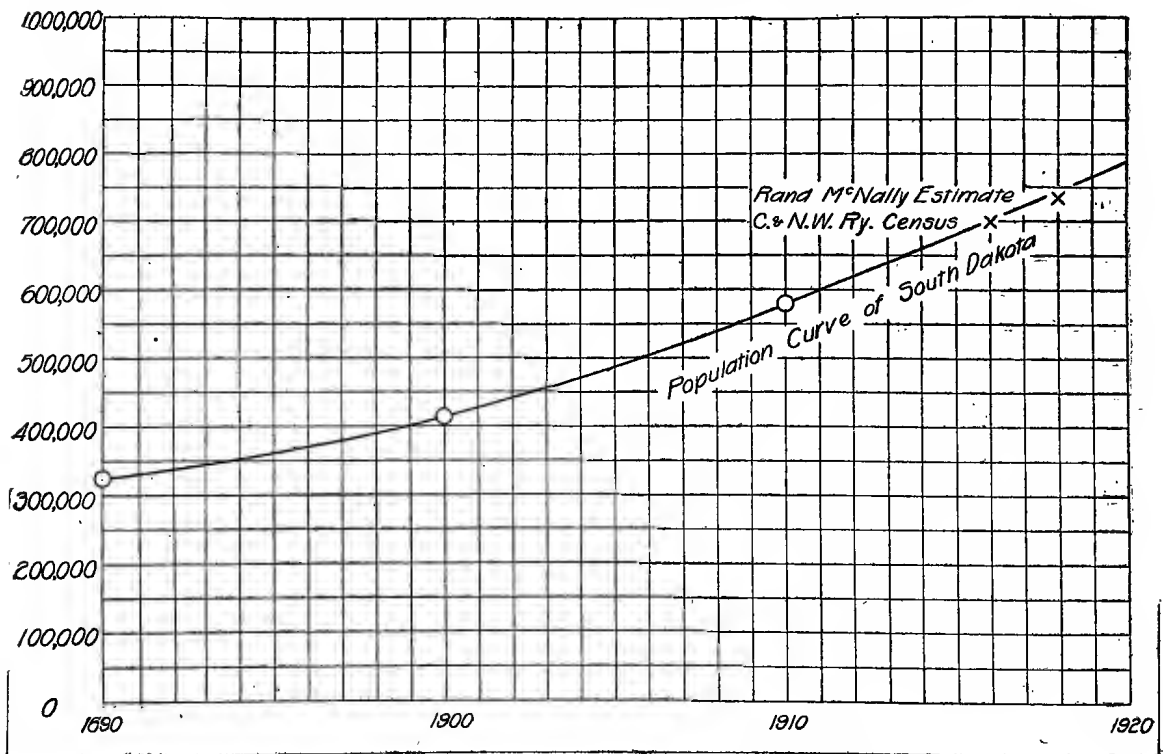


FIGURE 1-A. Growth of Population in South Dakota.

mission, the necessity of initially confining the service from the project to the eastern part of the State. *Even with this limitation it must be understood that the market east of the river is widely scattered and entails a comprehensive and costly system of power distribution to reach such market, and that any more extended transmission system will make the development entirely impracticable at the present time.*

A detailed analysis of the power market may be found in Appendix 1, including data of actual plant operation and such indirect and less authentic data as we were able to secure in lieu of plant records.

The estimated amount of power developed in the State east of the Missouri River in 1919 is based on our power survey supplemented with data taken from "Electric Power Development in the United States," Senate Document 316, part 2. Information of a pertinent nature has been compiled from numerous sources in addition, and the field of power exhaustively analyzed in view of all obtainable data.

TABLE I.

Estimate of Total Power Used in 1919 by the Larger Cities and Towns East of the Missouri River in South Dakota.

Cities.	Estimated Power Consumption in K. W. H.—1919	
1. Aberdeen—		
Light and power	2,890,000 KWH	
C. M. & St. P. Ry. Shops.....	250,000	
Total	3,140,000 KWH	
2. Armour (and ten adjoining towns).....	1,278,000	
3. Ashton (and eight adjoining towns).....	438,000	
4. Bradley (and eight adjoining towns).....	550,000	
5. Brookings	516,000	
6. Canton (and two adjoining towns).....	462,500	
7. Chamberlain (and one adjoining town).....	306,000	
8. Dell Rapids—		
Light and power	109,500	
Quarry load	65,000	
Total	174,200	
9. Elk Point	175,200	
10. Flandreau (and ten adjoining towns)		
Light and power	1,020,000	
Pumping	30,000	
Total	1,050,000	
11. Groton	182,500	
12. Huron—		
Light and power	1,750,000	
Pumping	457,000	
Total	2,207,000	

Power Used in 1919.

13

13. Lake Preston (and three adjoining towns)	400,000	
14. Madison	700,000	
		Estimated Power Consumption in K. W. H.—1919
Cities.		
15. Milbank—		
Light and power	365,000	
Milling	131,000	
Total		496,000
16. Mitchell		1,900,000
17. Mobridge		750,000
18. Parker		144,000
19. Pierre		1,270,000
20. Redfield—		
Light and power	794,000	
Milling	300,000	
Total		1,094,000
21. Sioux Falls (and adjoining district)—		
(Hydraulic and Steam power)	13,150,000	
Pumping	500,000	
Total		13,650,000
22. Tyndall		143,840
23. Vermillion		252,800
24. Watertown—		
Light and power	480,000	
Milling, Pumping, Etc.....	2,000,000	
Total		2,480,000
25. Wessington Springs		180,000
26. Woonsocket		151,800
27. Webster		275,000
28. Yankton		460,000
29. Forty-two other Small Towns.....		3,640,000
Total		38,467,000 KWH

A PRACTICAL TRANSMISSION LINE.

The transmission lines necessary to develop this market involve almost as large a financial outlay as the proposed power development itself. As a matter of fact, market and distribution present the critical problem in connection with this enterprise, upon the satisfactory solution of which the success of the entire project depends. The desirability of offering state wide service at the outset must give way

to the consideration of feasibility, and the costs of the water power development and of the transmission system must be curtailed in order that the selling rates of power may be made so attractively low as to induce holding companies of the present power utilities partially to abandon their own plants and to utilize the hydro-electric power of the state.

EXCLUSION OF OTHER SECTIONS ONLY TEMPORARY.

The limited scope of the proposed distribution (Figures 2 and 3) is not to construed as permanently excluding the smaller or more remote communities. Such of these as may organize to construct their own lines to the nearest available State transmission lines may, under favorable conditions, secure power at a cost which would be attractive. Obviously, if the length of transmission is considerable and the quantity of power comparatively small, the cost of power might be greater than would obtain with local isolated plants. The communities in the Black Hills have hydraulic power available for their present needs at a lower rate than that for which it could be transmitted to them from a state project, and the extension of service to that region from the state development should economically follow considerable growth in demand and is a subject for future consideration.

POSSIBLE POWER SITES.

The field investigation of the possible power sites included an examination of eight sites located as shown on the map, Figure 2, and described as follows:

Name of Site.

- | | |
|--------------------------|-----------------------------|
| 1. Medicine Butte | 8 Miles above Pierre |
| 2. Little Band | Cheyenne Indian Reservation |
| 3. Bad Hair | 18 Miles below Mobridge |
| 4. Mulehead | Mulehead Point |
| 5. Chamberlain | Chamberlain |
| 6. Reynold's Creek | 40 Miles below Pierre |
| 7. Mobridge | 4 Miles above Mobridge |
| 8. Big Bend | Brule Indian Reservation |

FIELD INVESTIGATIONS.

The field investigation of these sites included:

1. A reconnaissance survey of each of the prospective locations.
2. Comprehensive borings at each of the sites investigated.
3. Limited topographic survey of the sites with the exception of the Mobridge site, of which a full detailed survey was made.

A reconnaissance was made at each location in order to determine the best possible site, and at such site more detailed surveys were made. In each case it became essential to consider the possibilities of railroad connections from the nearest main line to the selected site; to locate the possible source of gravel and sand supplies; and to determine the detailed physical features which would modify safety and cost of

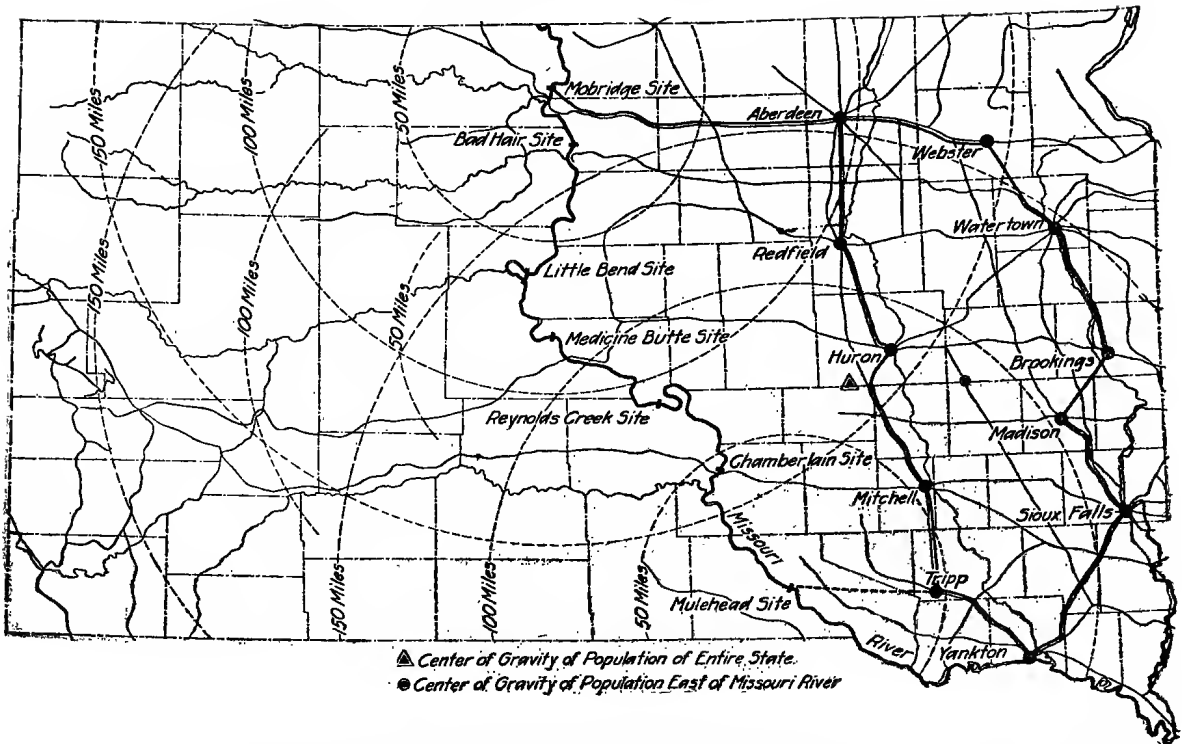


FIGURE 2. Locations of Damsites investigated and the Proposed Location of Substations and Primary Transmission Lines (110,000 volts).

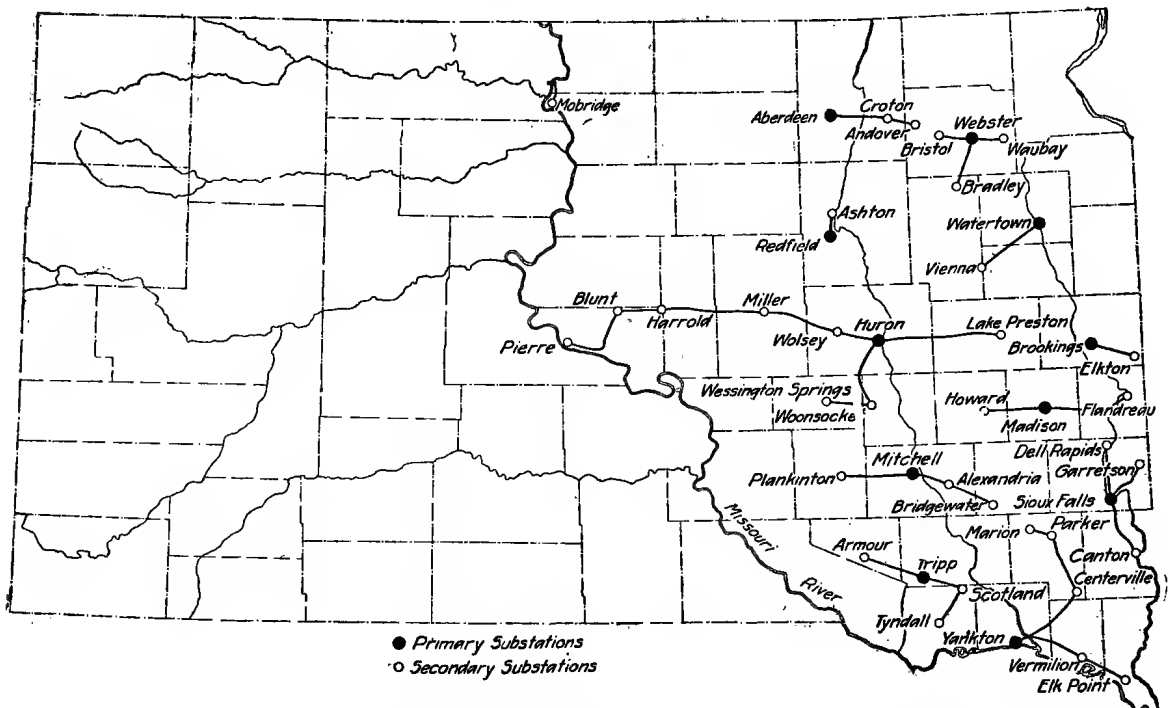


FIGURE 3. Proposed Location of Secondary Transmission System (33,000 and 13,200 volts).

development. Topographical surveys and sections were made at each site to ascertain the contour of the locality and the cross section of the channel, and borings and soundings were made to determine the nature of the foundation.

BORINGS.

From the first it was apparent that the data obtained from the investigation of the topography were not sufficiently indicative of the essential physical features of the site and since the economy of development at any of the sites depends upon the foundation conditions, borings were an essential part of the investigation, not only for the selected best site, as at first planned, but for all sites where developments were found practicable, in order to determine definitely the relative merits of each location. Borings were therefore made at each site, at least to depths beyond which steel sheeting could not be driven economically.

ORDER IN WHICH SITES WERE INVESTIGATED.

The initial work was done at the proposed Medicine Butte site about eight miles above Pierre, where the program of investigation much as outlined in the preceding paragraphs was carried out. Most of the time required in the investigation at Medicine Butte was required by the boring, and it was at this site that the hand boring-rig was tested and improved for use throughout the investigation of the other sites.

At Little Bend similar work was done and two possible canal routes were surveyed.

At the Reynold's Creek, Bad Hair, Mulehead and Chamberlain Sites, investigations similar to that at Medicine Butte were made in the order named. For sketches of the sites and the results of the borings, see Figures 14 to 19 in Appendix 2.

The conditions at Mobridge were investigated in still greater detail in order to afford a basis for preliminary designs and close preliminary estimates of cost.

STREAM FLOW OBSERVATIONS.

Pierre was selected as the point for our observation of the flow of the river. The flows were measured from a high water elevation of 5.0 feet in June to a low water level at the zero of the gage in September, 1919. In all nine gagings were made. The winter flow under ice was measured in February, 1920, and gave the least flow of which we have record.

PREVIOUS STREAM FLOW DATA.

There are but few studies and records available in regard to the flow of the Missouri River in South Dakota, and only limited data of the river flow in the states to the south. Such data as could be found have been analyzed, and the facts developed thereby that were applicable to our studies have been utilized for the purpose of this report.

The compilation of dependable stream flow data was the most difficult of the studies of this report. The available information was exceedingly meager and much of it inapplicable to the present needs for a continuous and reliable record of the river.

The Pierre records in "Daily River Stages" (a publication of the U. S. Weather Bureau) are not continuous to date, but we were able to supply the missing data for the last few years from the record of gage heights that has been kept by the Bridge Department of the Chicago and Northwestern Railway at Pierre.

At Mobridge the only data of river stages are those which have been kept by the Chicago, Milwaukee and St. Paul Railway since 1911.

As our chief concern has been to determine closely the flood flows and low water conditions of the river during years previous to 1919, we have exhausted every source of information that would give us data bearing on this subject. This entire matter is considered in detail in Appendix 3.

DESIRABILITY OF CONTINUOUS STREAM FLOW OBSERVATION FOR THE FUTURE USE OF THE STATE.

Because the data of the past are so meager, it is recommended that observations of the flow of the Missouri River be continued by the state in as complete and comprehensive manner as practicable, in order that some of the more obscure data may be clarified and that plans for future development may be founded upon accurate records that will be directly applicable to design.

CONDITIONS OF STREAM FLOW.

The extreme conditions of stream flow vary appreciably at different points on the river within the State, and these variations have important effects upon the economy of construction, maintenance and operation. The lower minimum flows to the north decrease the amount of continuous power output available at these sites, while the higher floods to the south necessitate greater flood capacities in spillways and thereby increase the cost of development at such sites.

At Mobridge, Pierre, and Mulehead, we estimate the average minimum flows at 6,000 second feet, 7,500 second feet and 8,000 second feet respectively, and the great floods that may occur once in perhaps fifty years we estimate at 300,000 second feet, 450,000 second feet, and 550,000 second feet, respectively.

FACTORS WHICH MUST INFLUENCE CHOICE OF POWER SITE.

1. *Geographic Location.*

The feasibility of water power development on the Missouri River in South Dakota involves the consideration of the total cost and operating expenses of a project constructed at the most favorable site. The scheme of transmission proposed for the eastern part of the State is necessarily so extensive that connection to it involves essentially the same ultimate cost of transmission from any point on the river within the State. The cost of transmission is a large percentage of the cost of development at any of the sites, exclusive of the Little and Big Bend sites, and since the requirements of the transmission system must be fixed by the State in making a development, the possible economy in the cost of development depends largely upon the economy of construction at the site selected, and relatively little upon its geo-

graphical location. However, since the bulk of the present available market is toward the east, the line losses would be less and the operating conditions somewhat better from sites on the river near the center of the State; but this consideration is of minor importance and our selection of a site is, for reasons hereinafter stated, based primarily upon cost of construction.

2. Foundation Conditions.

The foundation conditions beneath the normal sands and gravels of the river bed are most important; and while it is our judgment that a development can be made safely at any of the prospective locations, yet if a rock or shale bed is accessible at reasonable depths throughout the width of channel, the economy and safety of construction are greatly increased.

It is evident, from a study of the cross-sections at the various power sites (see Figures 14 to 19 inclusive), that at no site is a shale stratum uniformly at such elevation that the power house, spillway and lock can be founded economically directly upon it. Piling must therefore be used for foundation construction and a suitable cutoff must be provided in the sand and gravel to develop the head of water required and protect the foundation of the structures from destructive underflow.

Foundation on Sand and Gravel.

The head of water produced by a dam creates high pressure at the base of all structures in the river bed, and high porosity or channels in the sub-strata will induce the passage of water at abnormal velocities sufficient to erode and destroy the foundation unless it is properly protected. By extending a curtain wall or a series of walls of sheeting downward from the structure the direct path of the water through the river bed may be so obstructed and the length of the shortest path so increased that proper design will accomplish a reduction in the amount of underflow and permit with safety a slow and uniform seepage under the structures.

Foundation With Underlying Shales.

A complete cutoff may be secured by extending the curtain walls into an impervious underlying stratum where such exists and thus eliminate the uncertainties of sand and gravel foundations. On account of the superiority of this type, and the fact that steel sheeting of standard lengths can hardly be driven economically to depths greater than fifty feet, the foundation conditions at Mobridge are found to afford the most economical and the safest construction. Mulehead ranks second in this respect, and the remaining sites with their extensive beds of sand and gravel are quite similar to the conditions at Medicine Butte.

3. Power Conditions.

The lower minimum flows at the Mobridge site, which afford less continuous power, and the lower flood flows, which require less spillway capacity, combine to favor development at this site at a low first cost. While the practicable low water power of the stream at this location is less than at the southern sites, it will be suf-

ficient for the present needs of the market. In view of the limited market, the smaller development is desirable on account of low first cost for the initial project, provided the development will take care of future growth until the project has paid out and a second development is warranted by a further growth of the market.

The minimum continuous powers at Mobridge, Pierre, and Mulehead are, on the basis of a thirty foot head, estimated at 16,000, 20,000 and 23,000 horse-power respectively. Our estimate of the comparative flood flows at these places have been given in a previous paragraph.

The lower flood flows at Mobridge require a considerable less expenditure for spillway construction than that at the Mulehead site, although the reduction in the cost of development will not be proportional to the reduction in flood flow. The economy in the construction of the spillway may therefore be regarded as an economy additional to that due to superior foundation conditions.

4. *Overflowed Lands.*

The fourth factor in the cost of development is the flowage lands above the dam. When the water level is raised at the site 30 or 40 feet to develop the head required, the water level above the location is raised in comparatively decreasing heights until the effect essentially runs out thirty or forty miles above the dam. In times of flood the level is raised still higher and the flats along the river within thirty or forty miles upstream from the site will be subjected to continual or periodic flooding. The cost of these lands must be included in the cost of the project. Above Mobridge the character of the flowage lands is typical of the river lands in the northern part of the State and in North Dakota. There is little flat land of any considerable value and it is by far less extensive and less valuable than the lands at sites farther south. We estimate that one-half million dollars will secure the riparian lands above the Mobridge development, at an average cost of \$25.00 an acre, while at other locations such as Reynold's Creek, Mulehead or Big Bend, it is doubtful if the lands flooded can be bought either directly or by condemnation through the courts, for treble that amount.

5. *Railroad Facilities.*

The fifth consideration in the cost of a project is the railroad facilities. The great height of the bluffs along the river complicates the problem from an engineering standpoint. At some of the locations there are railroad lines on the flats along the river to which connection can be made at much lower costs. At each of the sites considered the following connections can be made:

a. by descent from the top of the bluffs

Little Bend	25 miles from C. & N. W. Railroad
Big Bend	17 miles from C. M. & St. P. Railroad
Reynolds Creek	17 miles from C. M. & St. P. Railroad
Bad Hair	5 miles from C. M. & St. P. Railroad

b. by lines constructed on the low lands

Medicine Butte 8 miles from C. & N. W. Railroad

Mobridge 1 mile from C. M. & St. P. Railroad

Chamberlain 1 mile from C. M. & St. P. Railroad

The most economical connections can be made, therefore, at the Mobridge and Chamberlain sites. In addition to the low cost of constructing the line, the short haul to serve the plants at these sites will materially reduce the expense of construction.

COMPARISON OF SITES.

From the previous discussion and the more detailed data which will be found in the appendices it therefore appears that the Mobridge site possesses the following advantages over the other sites on the river:

1. The better foundation condition due to the presence of shale near the surface will permit an effective cutoff by the use of sheet piling, particularly at the location of the spillway where the erosive effect will be most serious.

2. The cost of dam and spillway construction at this site will be less than at any other site.

3. The overflowed lands above the dam will be less in extent and materially less in cost than those of any other site.

4. The cost of railroad side track and the length of haul will be materially less than the cost at any other site except at the site near Chamberlain.

5. This site admits of the most economical development up to a capacity well within that required for perhaps ten or fifteen years in the future.

For these reasons the cost of development and the resulting cost of power from the Mobridge site is used as a basis for determining the feasibility of this project.

The Mulehead site is second in cost of development and should be the second site developed; and the remaining sites, except Big Bend and Little Bend, are essentially equal in safety and cost of development.

From the standpoint of operation there will be an advantage in developing the Medicine Butte location as the third development in combination with Mobridge and Mulehead, for the three together are so situated with reference to the market as to form the best combination of power sources for the proposed service.

The Big Bend and Little Bend sites at first seemed to offer the best power possibilities of any of the locations because the fall in the river around the bends might apparently be utilized by conducting the water from a pond impounded by a dam at the upstream side of the bend, across the neck of the bend, by a canal at Little Bend and by a tunnel at Big Bend. The tunnel proposed at Big Bend would, however, not provide for navigation at times of low water, and the quantity of excavation necessary to construct a canal at this site is prohibitive. At Little Bend two possible canal routes were surveyed (see Figure 20). The cost of constructing a canal on either route exceeded the total cost of the Mobridge development. The investigation of these sites was therefore abandoned in favor of more economical locations.

THE PROPOSED MOBRIDGE DEVELOPMENT.

Head Available.

The height of dam which has been selected for the development at Mobridge and upon which estimates of cost are based, would produce a normal head of thirty feet. By normal head is meant the head which would be available during times of average streamflow, or the head resulting from a normal flow of 13,000 second feet, which is approximately double the minimum flow. In this connection it should be stated that a development with a higher head, say to forty feet, is entirely practicable at this site and furthermore that the cost of power per unit of output, assuming the entire output sold, would be somewhat less with the higher head than with the lower head. Our reason for using a thirty foot head as a basis for this development is on account of the limited market and because of the necessity of keeping the cost of development at a minimum and of still developing a plant to a capacity sufficient to provide for the market for perhaps ten or fifteen years to come. If a larger market were available, or if upon further study it appears that the growth of load will warrant the cost of an installation at a higher head than thirty feet, the higher head development should be considered.

At this plant the head of thirty feet, will be increased during times of minimum flow to about 32 feet, due to the reduction in tailwater level by virtue of such flow; and during time of ordinary maximum flow, that is with a flood flow of 100,000 second feet, the head will be reduced to about 22.5 feet. This reduction in head is due to the fact that with the length of spillway necessary to pass the maximum flood, the rise in water above the spillway when passing the flood is considerably less than the rise in the tailwater due to the constriction in the channel at the Chicago, Milwaukee and St. Paul Railway bridge a few miles below this site. With a flood discharge of 180,000 cubic feet per second, the head will be reduced to about 18.5 feet. From such records as we have been able to obtain, it appears that only once since the year 1892 has a flood of such magnitude occurred and we estimate that a reduction in head to 18.5 feet will occur probably only once in about twenty-five years. As such maximum floods are of short duration, and of rare occurrence the consequent reduction in head and power is not regarded as serious.

Power Available From Average Flow.

In our detailed discussion of the streamflow of the Missouri River in South Dakota in Appendix 3 we have called attention to the fact that reliable data are not available of the flow of the river for past years. Without a record showing the variation in flow from month to month and from year to year, and covering a considerable period of years, it is impossible to make more than a general statement as to the amount of power that can be developed at the Mobridge site for each month of the average year under the conditions of head assumed. The power available, however, at the location under discussion, or in fact at any of the locations discussed in this report, during the periods of ordinary flow, is in excess of that required to provide for the market that is now available or will be available, for some years to come.

The average flow at Mobridge taking into account the effect of pondage may be estimated conservatively at 10,000 second feet, which is equivalent to 25,000 continuous horse power at the turbine shaft under a head of thirty feet.

Power Available From Minimum Flow.

From our investigation of the stream flow of the Missouri River it is our conclusion that a flow lower than 5,800 cubic feet per second at Pierre, will not occur more often than once every twenty-five years. The measured flow at Pierre reached a minimum in the fall of 1919 of 6,000 second feet, and the measured flow under ice conditions during the month of February, 1920, was 5,800 cubic feet per second. It is our judgment that a flow lower than that which has occurred the past season will not occur more frequently than about once every twenty-five years and, it is the judgment of many of the inhabitants of South Dakota, residing along the river, that the flow during the past season represents one of the lowest if not the lowest flow which has obtained during a period of probably fifty years. It is possible that at very infrequent periods, even perhaps once in fifty years, the streamflow may reach a lower quantity than obtained during 1919-1920. Such flows will, in our judgment, be of short duration if they ever occur and would have no important bearing on the feasibility of the project.

A flow of 5,800 cubic feet per second at Pierre, is equivalent to a discharge of 4,100 cubic feet per second at Mobridge, and the latter figure has been used as a basis for determining the power that would be available at the Mobridge site during times of minimum flow.

A dam thirty feet high at Mobridge would back the water up a distance of approximately thirty-five miles, and would create a pond of considerable capacity. It is obvious that with such pondage, by drawing down the head somewhat during times of minimum flow, the flow could be considerably increased for short periods. We estimate that with the pondage available during times of minimum flow of the past year there could have been developed at the turbine shaft 16,000 continuous horse power, and this amount of power by the aid of the pondage could have been maintained during the winter months of 1919-1920. Figure 4 is a hydrograph of the river at Mobridge, showing the average amount of water flowing each day from November 1, 1918, to March 1, 1920. Figure 5 is a power hydrograph showing the amount of power that would have been available continuously from eight of the proposed units utilizing the flow shown in Figure 4 under a thirty foot head and with the daily fluctuations modified by the pondage. We estimate therefore the power that is available from the minimum flow will not be less than 16,000 horse power except possibly at very infrequent periods.

Power Available During Flood Stages.

We have previously pointed out with a flood discharge of 100,000 second feet the head would be reduced to about 22.5 feet, owing to the excessive rise in tail-water. With this head each turbine unit would develop about 4,000 horse power which would

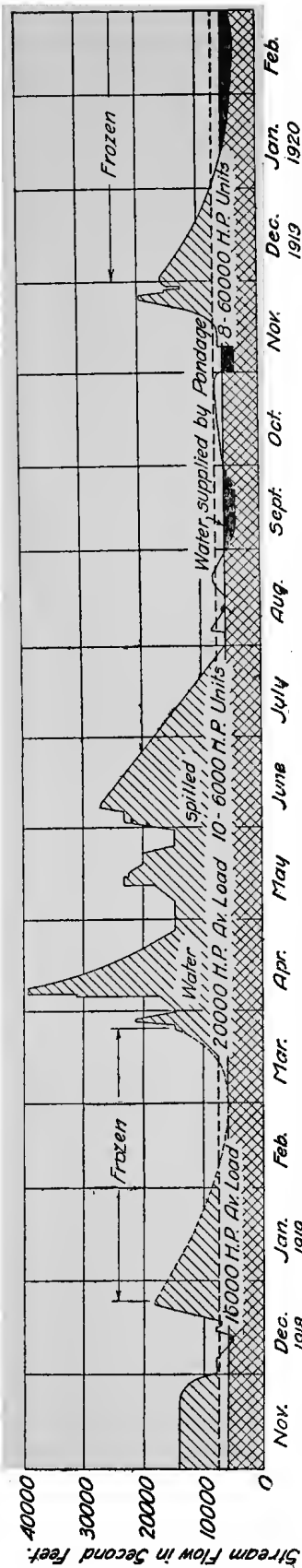


FIGURE 4. Approximate Hydrograph of Missouri River at Mobridge from November, 1918 to February, 1920, based on Pierre Records.
NOTE.—Elevation of upper irregular line of the diagram indicates approximate daily variations in rate of stream flow. Double cross hatched area indicates amount of water necessary to generate 16,000 continuous horse power at turbine shaft with 30 foot head. Solid areas indicate water not available from river flow but which could have been supplied from the storage in the pond above the proposed Mobridge dam.

Power Available.

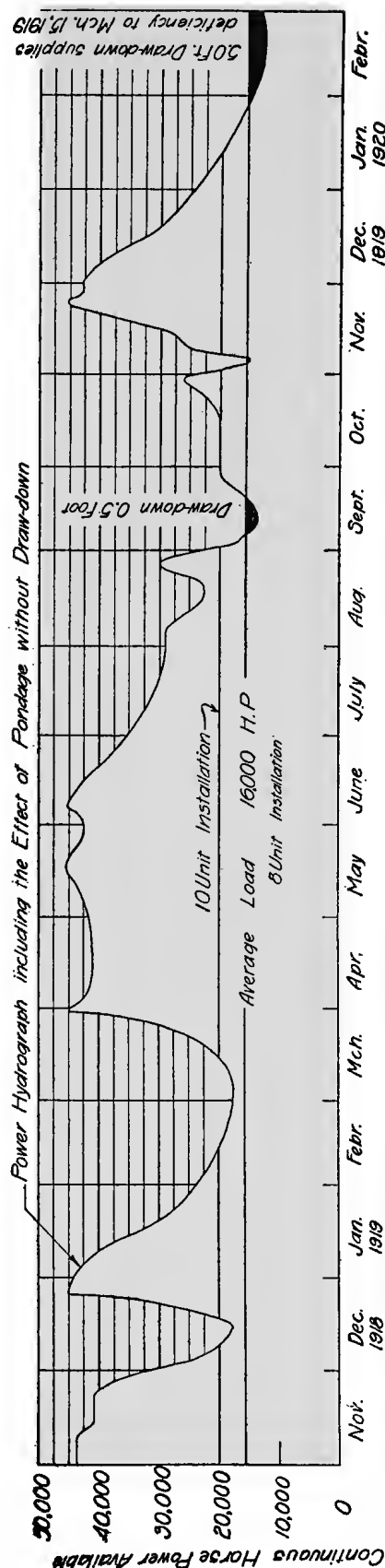


FIGURE 5. Approximate Power Hydrograph of the Missouri River from the Mobridge Hydrograph (Figure 4) on the basis of Thirty Foot Head.

be equivalent to 32,000 horse power with eight units or to 40,000 horse power with ten units. A flood of 100,000 second feet will not occur more frequently than once in every five years and would probably be of only three or four days duration. During conditions of high floods (180,000 second feet) which conditions have occurred but once since 1892, the head would be reduced to 18.5 feet and the power of each turbine unit would be reduced to about 3,200 horse power, equivalent to about 32,000 horse power capacity for the full installation of ten units. It should here be noted that each turbine unit proposed will produce at the normal head of thirty feet, about 6,000 horse power; so that the reduction in power by virtue of the reduction in head due to high flood flow is for the maximum conditions almost fifty percent.

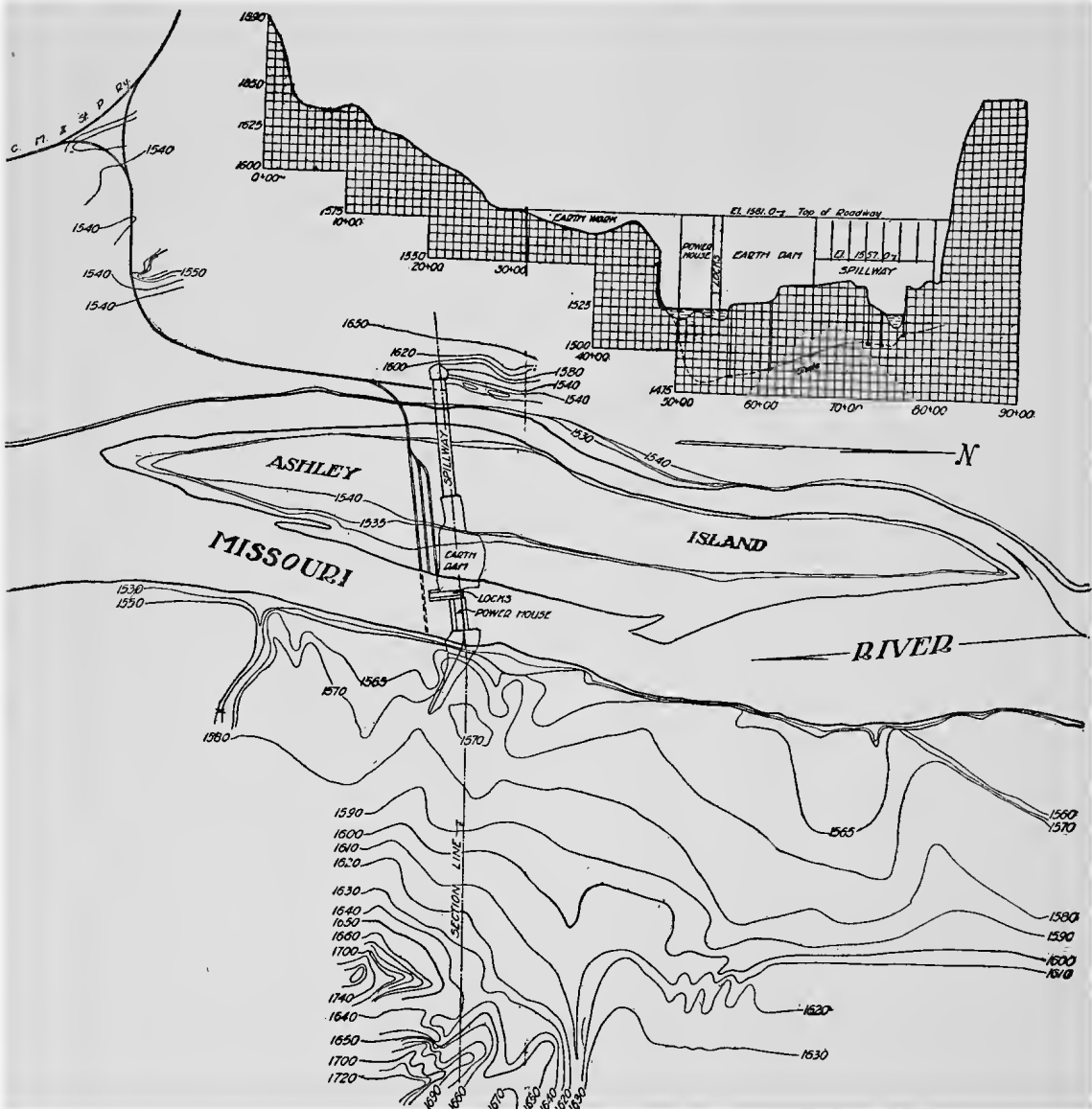


FIGURE 6. Section (upper) and Map of Suggested Layout of The Proposed Mobridge Hydro Electric Development Showing Sidetracks from C., M. & St. P. Railway.

PLANS FOR THE PROPOSED DEVELOPMENT OF MOBRIDGE.

1. General Layout.

Figure 6 shows the general layout of the proposed development at Mobridge. The construction extends across the channel through about the center of Ashley Island, and comprises the following features:

- a. A 1,400 foot dam and spillway, 1,456 feet long at the foundation, including two abutments.
- b. A power house 384 feet long.
- c. A lock 60 feet wide in the clear, 350 feet between hollow quoins and 121 feet wide over all.
- d. About 1,200 feet of earth dam with concrete core wall.
- e. A small amount of earth embankment at both ends of the structure.

It is proposed to drive steel sheeting, extending from the foundation concrete of each element of the structure into the underlying shale to protect the construction against underflow. The proposed elevation of the crest of the spillway is 1,557 feet above sea level and the elevation of the top of the earthwork and roadway will be at 1,581 feet elevation.

From the cross section shown in Figure 6, it will be noted that the maximum depth to shale in the main channel under the power house is about fifty feet.

The following considerations have determined the arrangement of the various structures in the channel:

- a. The spillway is placed in the west channel because on this side of the river the shale is nearest the surface and therefore any effects of erosion at the toe or downstream side of the structure will be less serious.
- b. The power house is placed in the main channel to provide a clear outlet for the tailwater from the draft tubes.
3. The lock is placed adjacent to the power house to assure a low water channel in the tail water for navigation purposes from and through the lock.

2. The Dam and Spillway.

The dam and spillway proposed will be of the OG hollow crest type, a section of which is shown in Figure 7. The cover and floor will be of reinforced concrete, and the bridge piers and the buttresses which support the cover and the weight of water will be of plain concrete. An important function of the floor shown under the buttresses is to provide a floodway and to prevent erosion of the foundation during construction. This general type of dam is, we believe, better adapted to the foundation conditions on the Missouri River than a dam of the gravity type.

The proposed spacing of bridge piers for the highway bridge spans is 200 feet, giving six piers on the crest of the spillway which reduces its clear width by forty-eight feet at the crest and thirty feet at the stage of flood capacity. The buttresses supporting the deck or cover of the spillway will be three feet thick and are spaced 12.5 feet center to center between piers.

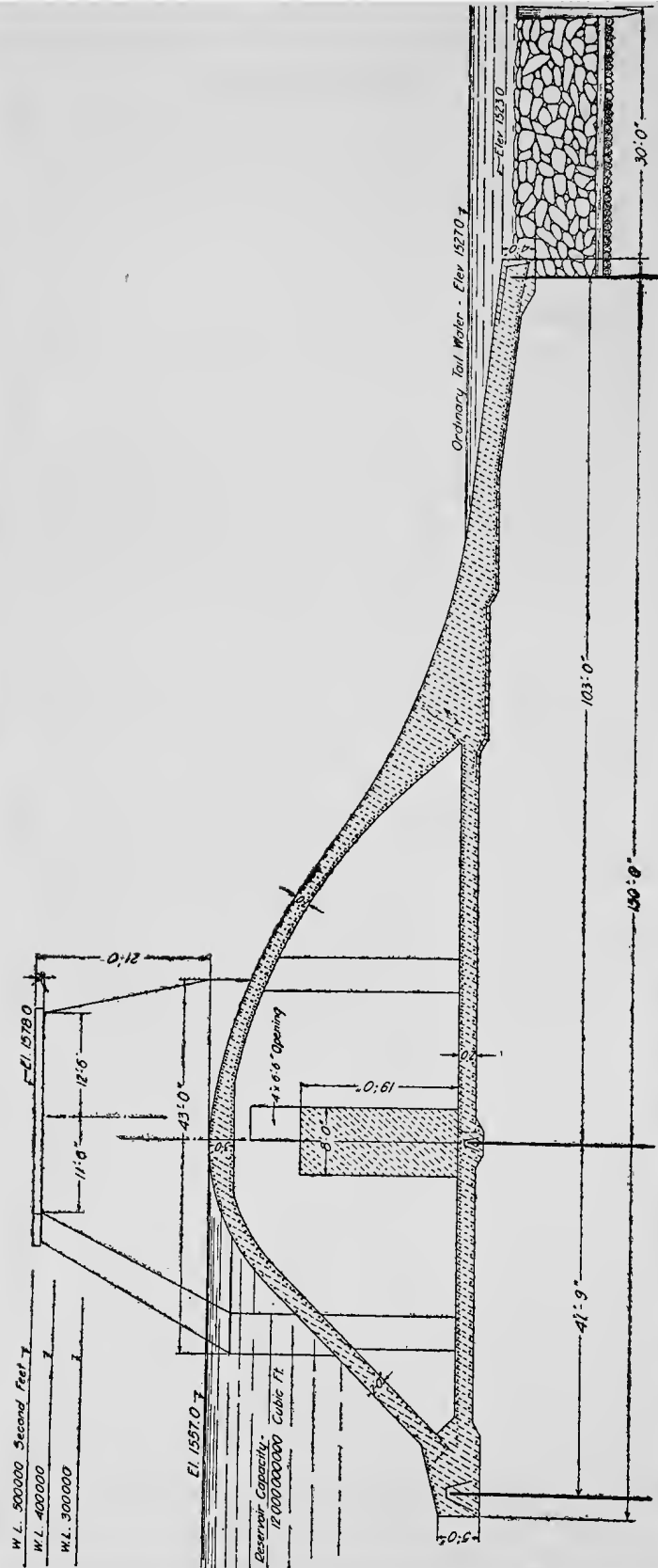


FIGURE 7. Cross Section of Proposed Dam at Mobridge Showing Piers for Bridge and Location of Sheet Piling (Foundation piling not shown).

Throughout the length of the spillway an average length of twenty-five feet of sheeting is required to form a cutoff into the shale formation. One line of steel might make an effective cut-off beneath the spillway, but from our experience in driving sheeting through gravel strata, it is our judgment that the second line should be driven as a precautionary measure and as an increased assurance that leakage will be controlled and will not develop with time into a source of danger.

The third line of sheeting under the toe of the apron below the dam may prevent to some extent the development of uplift pressure on the dam during abnormal tailwater, but its principal function is to protect the material beneath and below the apron from the scouring effects of flood waters from the spillway.

We have previously pointed out that during flood discharge the headwater rises more slowly than the tailwater and reduction of head results. It is therefore desirable to make the spillway of the shortest practicable length in order to counteract the effect of the reduction in head so far as practicable and at the same time provide an adequate passage for any flood discharge that is likely to occur. The length of spillway suggested is such that, with a rise of twenty-one feet over the crest it will discharge 500,000 cubic feet per second which is perhaps a sixty percent. greater discharge than has ever occurred on the Missouri River at this site.

In the event of a discharge exceeding 500,000 second feet (which in our judgment is not probable), the flood level of the pond may rise two feet more, or to a total height of twenty-three feet, without over-topping the earthwork. It is believed, therefore, that the flood capacity provided is ample and much greater than any flood that is likely to occur.

A question might be raised as to the effect of flood discharge at the toe of the spillway. It is our judgment that the erosive effect at the toe is less serious during times of great floods than at times of ordinary floods because of the rise in tailwater and the cushioning effect of the greater depths of water. It will be noted that we have also provided a mat and boulder fill sustained by piling for a distance of thirty feet down-stream from the toe of the spillway in order to further protect the structure at this point.

3. Power House and Machinery.

The power house upon which we have based our estimate of cost is shown in section in Figure 8, and in elevation and plan in Figures 9 and 10. It is tentatively designed for ten units each consisting of a 6,000 horse power single vertical turbine runner, approximately 108 inches in diameter and operating at approximately seventy-eight revolutions per minute. Each turbine will be direct connected to a 5,400 kilo-volt-ampere vertical type generator which will deliver 3-phase, 60-cycle alternating current at 6,600 volts pressure. The step-up transformers for increasing the voltage to 110,000 volts, the transmission voltage that has been selected to transmit the power within the district contemplated, will also be located in the main station. The main switch board for controlling the various electrical units will be located in the

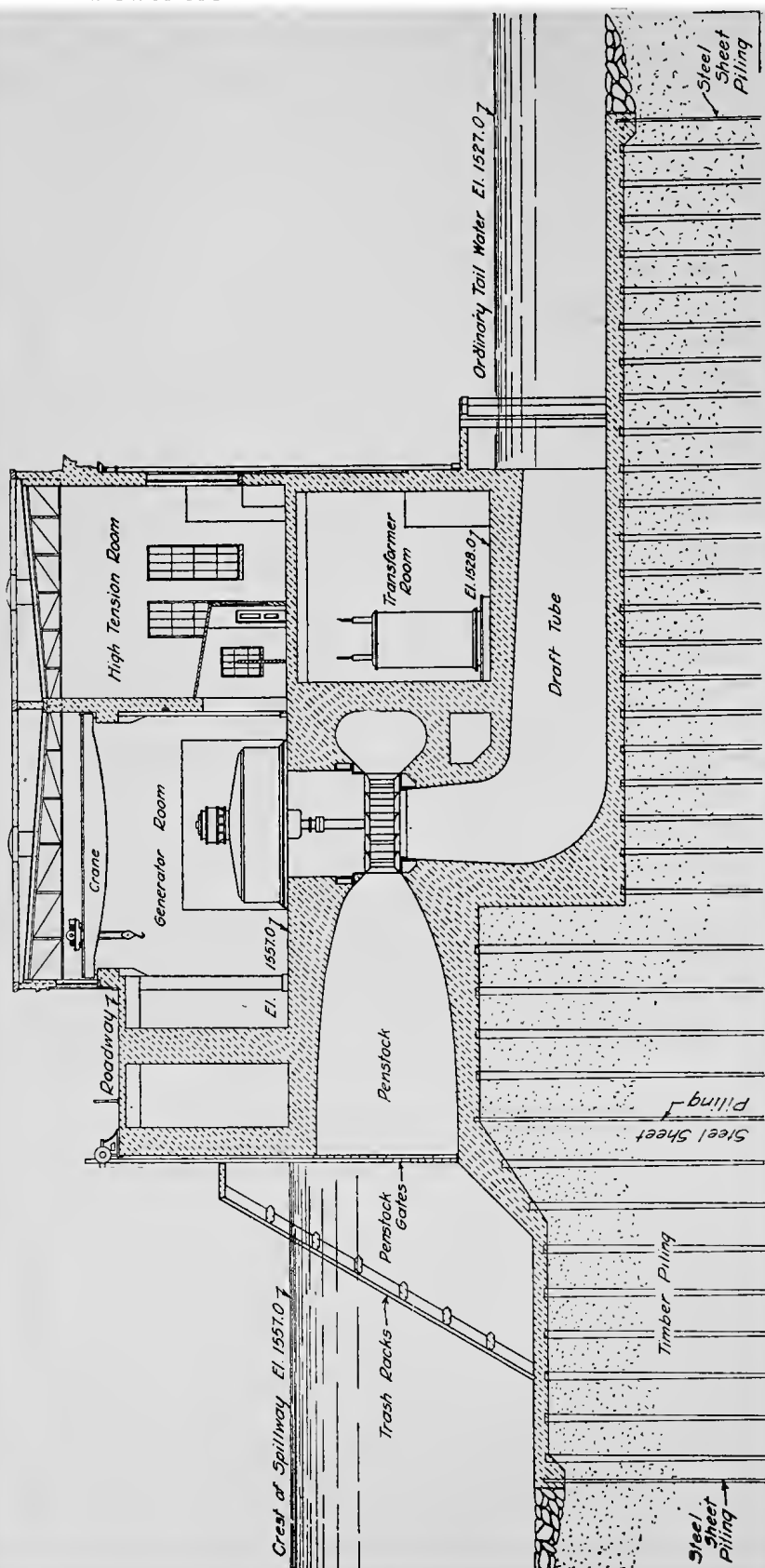


FIGURE 8. Cross Section of Proposed Power House at Mobridge Showing General Construction of Station, Driveway and Foundations and Arrangement of Machinery and Equipment.

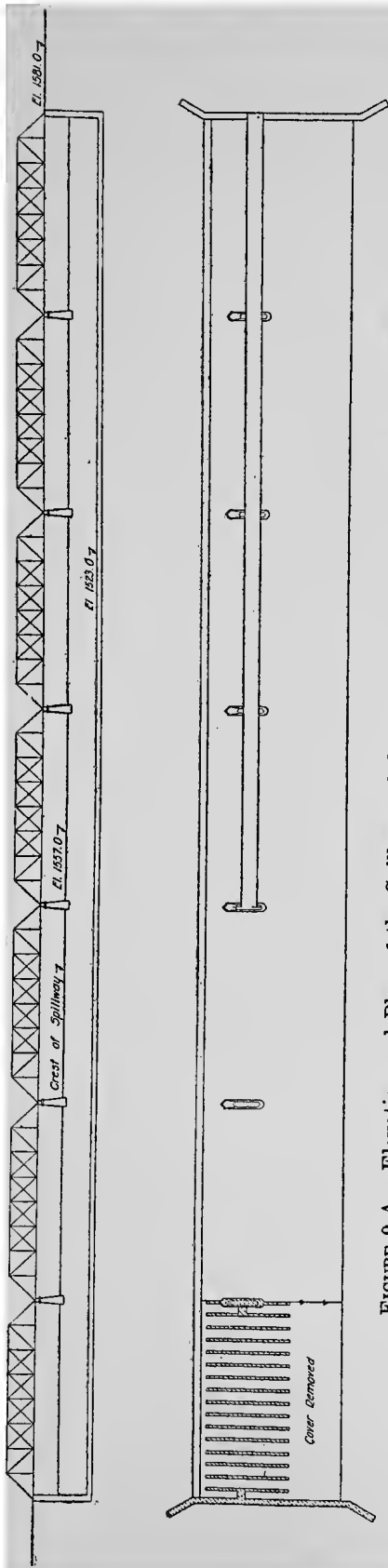


FIGURE 9-A. Elevation and Plan of the Spillway of the Dam and the Highway Bridge over same.

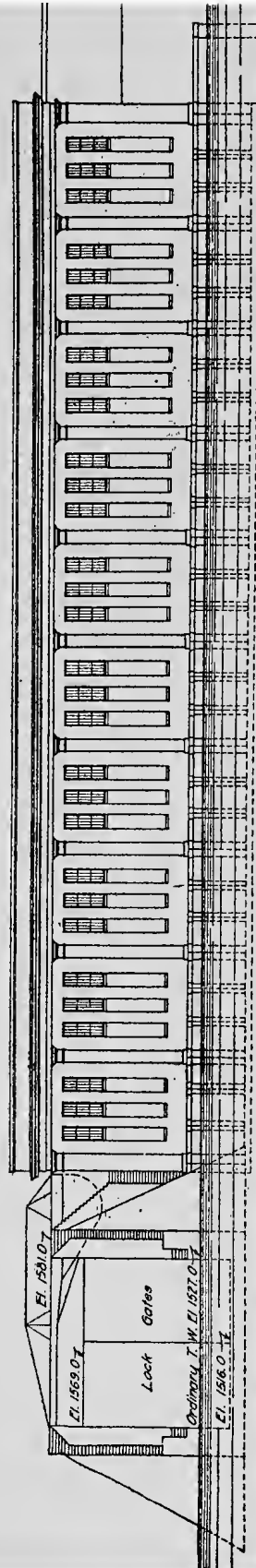


FIGURE 9. Elevation Showing Proposed Power House at Mobridge and Location of Navigation Lock.

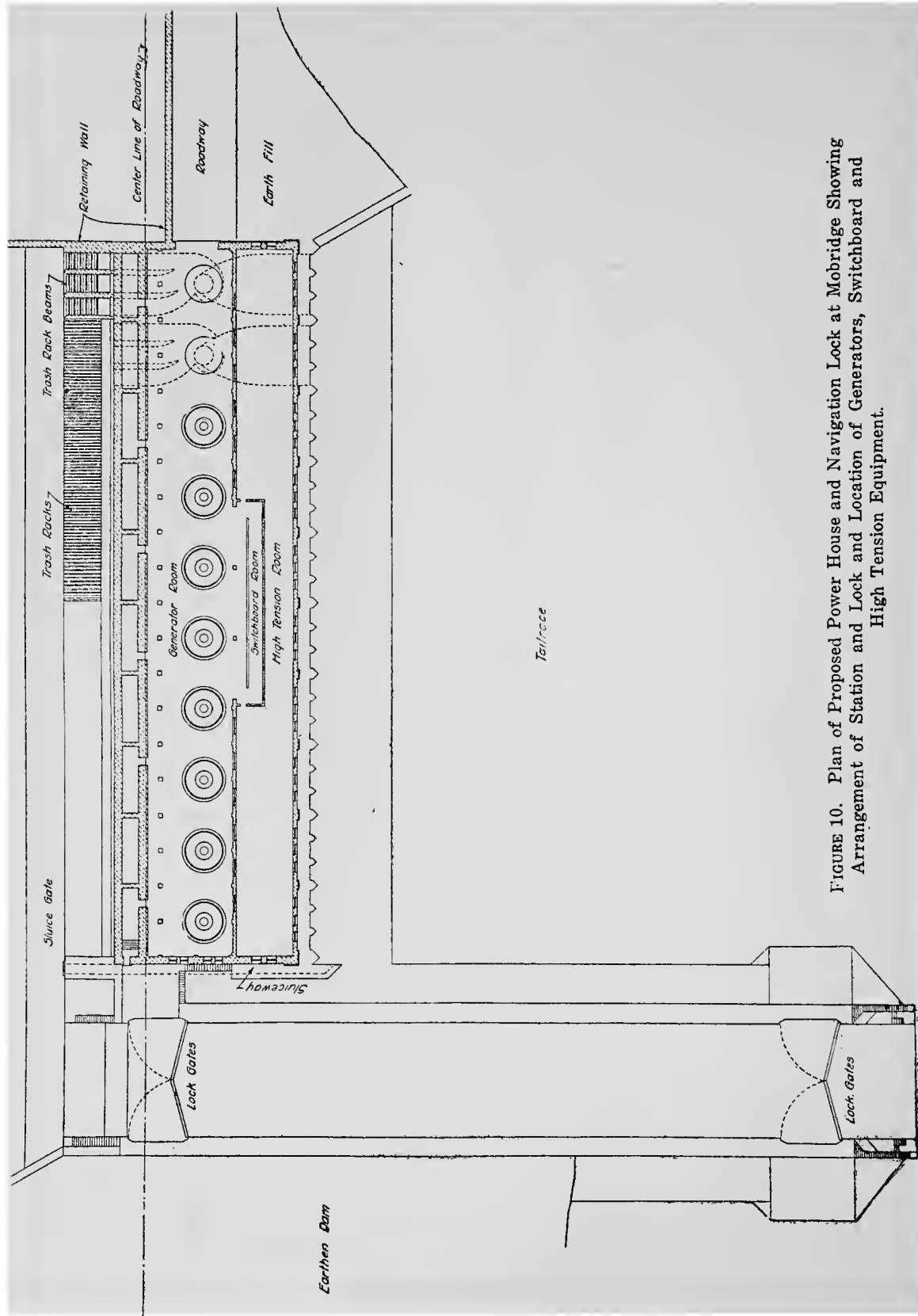


FIGURE 10. Plan of Proposed Power House and Navigation Lock at Mobridge Showing Arrangement of Station and Lock and Location of Generators, Switchboard and High Tension Equipment.

main power station with other auxiliary machinery such as lightning arresters, switches, transformers, etc.

The estimates of cost are based upon an initial installation of eight of the units, leaving two units to be installed later. Future consideration may show the desirability of installing even fewer units at first.

4. Load Factor.

In connection with the proposed machine installation it is desirable for a full understanding to refer to the matter of the load factor for which provision has been made. The term "load factor" may be defined as the ratio of the average load to the peak load and the factor which will obtain will materially effect the machine capacity of the plant. We have previously estimated the average low water capacity at the turbine shaft at 16,000 continuous horse power. By continuous power is meant power uniformly used throughout the entire 24 hours of each day. It is obvious that if the load were constant a machine capacity of 16,000 horse power is all that would be necessary to furnish such power. If, however, the load is variable as it undoubtedly will be and equals say 8,000 horse power for twelve hours and 24,000 horse power for twelve hours of each day, the average load would still be 16,000 horse power, but a machine capacity of 24,000 horse power would be necessary to fulfill the requirements of the power demand. Under these conditions the load factor would be 66 $\frac{2}{3}$ percent. The load factor that obtains on the electric plant of an average small city is frequently not above twenty-five percent and often much lower. Where there is a considerable industrial or factory load in connection with the lighting load, the load conditions are improved and the load factor increased. It is obvious, therefore, that the character of the load is an important factor in the determination of necessary machine capacity. The greater the load factor the less the machine capacity required, and the less the load factor the greater the amount of machinery required. The machine capacity suggested for the first installation, namely 48,000 horse power is sufficient to provide for an average continuous load of 16,000 horse power at the turbine shaft with a load factor of 33 $\frac{1}{3}$ percent which is assumed as the load factor under which the plant will ultimately operate, though further study may modify this figure somewhat.

During the reduction in head previously discussed such reduction is necessarily accompanied by a reduction in power and therefore in the continuous power output that is available. Due to such reduction, the capacity of each turbine unit will be reduced from 6,000 to 3,200 horse power perhaps once in twenty-five years and to about 4,200 horse power once in five years. The full installation of ten units which is proposed for the ultimate installation would therefore, under the condition which obtains once in five years, be capable of delivering 42,500 horse power at the turbine shaft or essentially the machine capacity of eight units under the normal conditions of head. While it is doubtless true that at infrequent periods of say once in fifty years, a flood of greater magnitude than has been estimated may occur, it is not be-

lieved that such floods should be used as a basis for determining the maximum machine capacity which should be provided, for even though they may occur their period of duration would be short, not more than two or three days, and the extra cost involved is therefore unwarranted.

From the above discussion it appears that the machine capacity suggested is well adapted for the low, ordinary, and flood flow conditions that will normally obtain. Further study of the problem may show some changes desirable, such as increase in the size of the units, increase in the number of units, or a development to a greater head than the thirty feet contemplated. The proposed installation seems adequate for the probable power needs for the next ten years or more considering a normal growth, and is we believe a fair basis for our estimates and for the consideration of the feasibility of the project.

5. *Lock for Navigation Purposes.*

The federal requirements for a lock for navigation purposes on the Upper Missouri were obtained from the Chief of Engineers, Washington, D. C., by the Hydro-Electric Commission of the State. The following dimensions of the lock proposed conform, we understand, to the requirements made by the Chief of Engineers with direct reference to this project.

Length between hollow quoins	350 feet
Width of lock chambers	60 feet
Depth on lower miter sill	7 feet

It is proposed to construct this lock of plain concrete, and its gates of steel, and to protect the foundation beneath the lock by surrounding it completely with a single line of steel sheeting driven into the shale. (See Figures 9 and 10.)

6. *Bridge and Roadway.*

Provision has been made in the system of structures at the site for a bridge and roadway for wheel and pedestrian traffic across the river in accordance with the requirement of the statute of the state as follows:

- a. All earthwork proposed will be graded on top and surfaced to form a sixteen foot roadway.
- b. A sixteen foot width of roadway around the power house is designed to carry the usual highway loads.
- c. A trunnion Bascule lift, sixteen feet wide, supported between the power house and the left wall of the locks, will span the lock.
- d. Seven two hundred foot spans of highway bridge, with reinforced concrete roadway sixteen feet wide will bridge the spillway.

The roadway is carried at elevation 1581, three feet above the estimated maximum flood height of the pond at which the spillway will discharge 500,000 cubic feet per second.

7. *Transmission System.*

The proposed transmission system includes a duplicate three-phase, 60-cycle, 110,000 volt line from the Mobridge site to Aberdeen, and a single three-phase loop line with primary substations at Aberdeen, Redfield, Huron, Mitchell, Tripp, Yankton, Sioux Falls, Madison, Brookings, Watertown and Webster, as shown on map, Figure 2. The secondary lines and substations for the initial development, which would probably be at 33,000 volts or lower, are shown on map, Figure 3.

Our estimates are made on the basis of using H-type construction of wooden poles for the line supports with average spans of about 400 feet and with seven suspension discs per insulation. Each series of insulator discs is to be protected by arcing rods. Two steel ground wires are to be carried on steel bayonets extending above the top of each pole with a steel cable of the same size carried down the pole from the bayonet to a ground plate located in the moist dirt near the bottom of the pole. In order to reduce the chances of interference with telephone and telegraph lines, it is proposed to transpose the main lines at intervals of two to four miles.

In order to decrease the chance of failures on the line, causing interruptions to service, it is proposed to make the main trunk feeder from Mobridge to Aberdeen of duplicate three-phase lines, each consisting of three No. 00000 aluminum cables, steel reinforced, and two $\frac{1}{4}$ " double galvanized Siemens-Martin steel strand ground wires. At Aberdeen a special outdoor substation and switching station is provided for in our estimate. This substation will be so arranged that either or both of the trunk feeders may furnish current to either or both branches of the loop line in addition to a feeder for Mobridge and two feeders for the territory within the Aberdeen district. At each of the remaining ten primary substations, we have estimated on an outdoor type of substation with switches on either side so that sections of the line may temporarily be cut out for repairs or alterations at any time without interrupting service to any point on the system.

As it is not economical to supply small towns and villages, having a peak load of less than 500 kilowatts, directly from the 110,000 volt line, we have provided for secondary lines radiating from the eleven main substations or distribution centers to the more important loads in their vicinity. (See Figure 2).

ESTIMATE OF COST OF DEVELOPMENT AND OF TRANSMISSION LINES.

Our detailed estimates of the cost of development as proposed at Mobridge are given in Appendix 4, with more approximate estimates of similar development at Mulehead and Medicine Butte. The quantities have been estimated from preliminary plans for the installation that we have considered most desirable under the existing conditions. The final design may change our estimated quantities somewhat, but we believe that, on the whole, our preliminary plans represent closely the most practicable layout.

The unit prices used in our estimates have been secured:

a. From tentative quotations which have been requested and received from vari-

ous manufacturers, and which have been based on our plans for this development. These include prices on the hydraulic and electrical machinery and equipment.

- b. From current prices on construction materials and actual prices paid for such materials, machinery and equipment for other similar projects.

In our estimates of cost we have included liberal unit prices for labor, materials and machinery, a liberal contingent fund, and an estimate of about \$1,000,000 for interest during construction. The latter item may possibly be reduced if bonds can be issued and sold only as the funds are needed but will be increased if the entire quantity of bonds needed are issued before construction is begun.

It is possible that those unfamiliar with hydraulic construction, who may examine our estimates, as given in some detail in Appendix 4, may conclude that even under existing conditions the unit prices used are unduly large. Our personal experience in the design and construction of hydro-electric plants has taught us that there are many and diverse contingencies that arise in such construction which can be provided for by the use of liberal unit prices. It should also be noted that these prices cover the cost of many minor items and expenses which cannot well be tabulated or included in a preliminary estimate with only outlined plans as a basis. The problem of making an estimate at this time, when prices are rapidly fluctuating and may increase or decrease materially in the near future, finds its best solution in liberal unit prices which we have endeavored to use.

It is of course obvious that a continued rise in the cost of labor, material and machinery may in the next year or so render even the liberal prices we have used inadequate for the construction of the proposed development. It is also obvious that a return of the country to a sound and sane business basis may so reduce costs as to render our estimates too large. Our estimates, we believe, are adequate to cover actual cost at the present time. The estimated cost of the development at Mobridge and of the complete transmission system is given in outline in the following table. A more detailed estimate will be found in Appendix 4.

COST OF POWER FROM THE PROPOSED MOBRIDGE DEVELOPMENT.

1. Unit Cost Based on the Total Cost of the Installation.

In estimating the cost of power we have assumed interest on the investment at five percent., depreciation on the water power development at one percent., and on the transmission lines and substations at five percent., and the cost of operation and maintenance at one percent. These percentages equal a total of seven percent. on the cost of the hydro-electric development and eleven percent. on the cost of the transmission and distribution system.

Based on our estimated cost of \$9,103,000 for the water power development and of \$7,044,000 for the transmission system, or a total cost of \$16,147,000 for the entire installation, the annual cost of power regardless of the total output generated and sold would be \$1,412,050. Based on this annual cost and on our estimate of the total

The Mobridge Development.

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probable output of the Mobridge plant, of 87,600,000 kilowatt hours per annum, the resulting unit cost will be 1.60 cents per kilowatt hour when all the power is sold.

TABLE 2.

Estimated Cost of Mobridge Development.

30-Foot Head.

Dam and Spillway	\$1,558,982
Highway Bridge	378,017
Power House (Provision 10 Units).....	1,218,973
Machinery { Turbines Generators Transformers Switches Switchboards Lightning Arresters Crane	1,445,000
Lock	928,630
Abutments	204,560
Earth Embankment	850,170
R. R. Service Spur	48,660
Cofferdam and Pumping	300,000
Flowage	500,000
	\$7,432,992
Engineering, Contingencies, and Interest during Construction	1,670,008
Total (Exclusive of Transmission).....	\$9,103,000

The Estimated Cost of Transmission System

Trunk Line Transmission Line	\$ 994,440
Loop Line Transmission Line	2,207,900
Secondary Transmission Line.....	1,647,060
Primary Substations	904,500
Secondary Substations	100,000
	\$5,853,800
Engineering, Contingencies and Interest during Construction	1,190,200
Total for Transmission	\$7,044,000

Total cost of development and transmission system \$16,147,000.

2. Unit Cost Omitting Secondary Transmission System.

The estimated cost of the secondary transmission lines and substations, that is of the low voltage lines radiating from the main transmission system, is \$2,100,000 which is about thirteen percent. of the entire estimated cost of development with the complete transmission system.

If this secondary transmission system can be built at the expense of the local communities using the power, the cost of the same can be eliminated from the cost of the complete system we have outlined. In such a case, the unit costs for power would be reduced from 1.60 cents to 1.34 cents per kilowatt hour on the basis of the sale of the entire output. In this case the current would be delivered by the State to the eleven main substations leaving the secondary lines and substations to be constructed by the company or community purchasing the current. The ultimate cost to the customer would, in the end, be practically the same. Should this arrangement be considered, it must be borne in mind that such secondary system ought to be built and maintained under strict State supervision, and on specifications which should require proper and uniform construction. Even under such conditions we fear that difficulties might arise which would be obviated by the construction and ownership of such lines by the State.

3. Unit Cost Omitting the Cost of Bridge and Roadway.

Our estimates of costs of development have included the cost of constructing a highway bridge over the Missouri River in connection with the dam and power station and in accordance with the requirement of the statute. In the case of the Mo-bridge development, we estimate that the highway bridge will add approximately \$550,000 to the cost of development, and this added investment has been included in the total investment on which our estimates of the cost of power are based. Obviously, this is not logical as the bridge will serve an important purpose for which a reasonable fixed charge based on its cost should be borne by the State. The bridge so constructed will cost much less than it would if constructed independently from the dam, for under the latter condition the dam provides for foundation for the bridge. It would seem therefore that at least the actual cost of the bridge, and logically some allowance for foundations, should be eliminated from the capital charges of the power project. The effect of the elimination of the actual extra cost of the bridge would reduce the cost per kilowatt hour of the total output about two percent. and would result in a unit cost of 1.56 cents per kilowatt hour based on the cost of the water power installation and total transmission system, or 1.30 cents per kilowatt hour based on the cost of the water power installation and high voltage transmission system only.

4. Unit Cost Omitting Item of Depreciation.

During the early years of the development of the market, only a portion of the total output of this plant can be sold and perhaps ten years or more will elapse before a market will absorb the total output of 87,600,000 kilowatt hours per an-

num. In the meantime the power actually sold must carry the entire cost of fixed charges and operating expenses.

In this connection it should be noted that the actual depreciation of plant and equipment will be small in the early years of operation and may well be reduced or entirely eliminated in the early years and increased in later years as the annual output of current increases.

Omitting depreciation, the unit cost of current based on the total output, would equal 1.10 cents per kilowatt hour and this omission would also reduce the unit cost of the reduced output as will be hereafter shown.

5. *The Present Market and Its Effect on Unit Costs.*

We estimate that if the proposed plant had been ready for operation in 1919 it might have replaced an annual output, produced from fuel, of 30,000,000 kilowatt hours. This is approximately one-third the normal output that would be available from the Mobridge development. Based on this output and the fixed charges previously estimated, the unit costs of power would be increased to nearly three times or to about 4.70 cents per kilowatt hour instead of 1.60 cents per kilowatt hour. If the secondary lines and substations were eliminated, the unit cost for power delivered on the basis of 30,000,000 kilowatt hours per annum would be reduced to 3.90 cents per kilowatt hour. If we assume a ten percent. increase in power requirements each year under these conditions the difference in cost of 4.70 cents per kilowatt hour (the cost based on 30,000,000 kilowatt hours annual output) and 1.60 cents per kilowatt hour (the cost on the basis of the entire output) or 3.1 cents per kilowatt hour would be reduced at the rate of .31 cents per kilowatt hour per year, and would become 1.60 cents per kilowatt hour at the end of the ten-year period.

It is quite evident that, on the basis of an annual output of 30,000,000 kilowatt hours, and a reasonable price for current, sufficient revenue would not be available to pay the total fixed charges and operating expenses. If during the early years of operation, the depreciation charge was omitted, the annual charges would be reduced to six percent., of which five percent would be interest charges and one percent. operation expenses. Under these conditions the annual charges based on the total cost of \$16,147,000 would be \$968,820. On this basis and an annual output of 30,000,000 kilowatt hours, the unit cost to the State would be 2.23 cents per kilowatt hour, and if the item of secondary lines and substations be eliminated the unit cost would be reduced to 2.79 cents per kilowatt hour.

6. *Comparative Costs of Power from Various Complete Developments, Under Various Conditions of Load, Based on Interest, Depreciation, and Operating Charges.*

Table 3 shows the cost at which power can be delivered from the Mobridge plant under different conditions of load, on the basis of the full development previously outlined and including interest, depreciation and operating expenses. The table also shows the similar cost which would obtain if the Mobridge plant were constructed

with a forty foot head, and also the similar cost that would obtain if instead of the Mobridge development a plant was constructed at the Mulehead or at the Medicine Butte sites.

TABLE 3.

Cost of Power Based on 7% Annual Charges on Plant Cost, 11% on Cost of Transmission System and 33½% Load Factor.

Kilowatt hours per year	30,000,000	53,000,000	87,600,000	100,000,000	117,000,000
Cents per KWH from Mobridge development with 30 ft. Head.	4.70	2.66	1.60	....	....
Cents per KWH from Mobridge development with 40 ft. Head.	5.24	2.97	1.80	1.57	1.35
Cents per KWH from Mulehead development with 30 ft. Head.	5.26	2.98	1.78	1.58	1.35
Cents per KWH from Medicine Butte development with 30 ft. Head	5.70	3.23	1.95	1.71	....

7. *Comparative Costs of Power From Various Developments, Under Various Conditions of Load, Omitting Secondary Transmission System But Including Interest, Depreciation and Operation Charges.*

Table 4 gives data similar to that in Table 3 for these various conditions but with the secondary transmission system eliminated.

TABLE 4.

Cost of Power on Basis of 7% Annual Charges on Plant Cost, 11% on Cost of Transmission System and 33½% Load Factor.

(Not including Secondary Transmission System.)

Kilowatt hours per year	30,000,000	53,000,000	87,600,000	100,000,000	117,000,000
Cents per KWH from Mobridge Development with 30 ft. Head.	3.90	2.21	1.34	....	....
Cents per KWH from Mobridge Development with 40 ft. Head.	4.44	2.52	1.52	1.33	1.14
Cents per KWH from Mulehead Development with 30 ft. Head.	4.45	2.52	1.52	1.34	1.14
Cents per KWH from Medicine Butte Development with 30 ft. Head	4.90	2.77	1.68	1.47	....

8. *Comparative Costs of Power From Various Complete Developments, Under Various Conditions of Load, Based on Interest and Operating Charges, Depreciation Omitted.*

Table 5 gives data similar to that in Table 3 but omitting the item of depreciation.

TABLE 5.

Cost on Power on Basis of 6% Annual Charges on Entire Investment and 33½% Load Factor.

Kilowatt hours per year	30,000,000	53,000,000	87,600,000	100,000,000	117,000,000
Cents per KWH from Mobridge Development with 30 ft. Head.	3.23	1.83	1.10	....	....
Cents per KWH from Mobridge Development with 40 ft. Head.	3.69	2.09	1.26	1.11	0.95
Cents per KWH from Mulehead Development with 30 ft. Head.	3.76	2.13	1.29	1.13	0.96
Cents per KWH from Medicine Butte Development with 30 ft. Head	4.08	2.31	1.40	1.22	....

9. *Comparative Costs of Power From Various Developments, Omitting Secondary Transmission System and Including Interest and Operating Charges, Depreciation Omitted.*

Table 6 gives data similar to that in Table 4, but with the item of depreciation omitted.

TABLE 6.

Cost of Power Based on 6% Annual Charges on Investment and 33½% Load Factor. (Not including secondary Transmission System.)

Kilowatt hours per year	30,000,000	53,000,000	87,600,000	100,000,000	117,000,000
Cents per KWH from Mobridge Development with 30 ft. Head.	2.79	1.58	0.96	....	....
Cents per KWH from Mobridge Development with 40 ft. Head.	3.25	1.84	1.12	0.98	0.83
Cents per KWH from Mulehead Development with 30 ft. Head.	3.32	1.88	1.14	1.00	0.85
Cents per KWH from Medicine Butte Development with 30 ft. Head	3.65	2.07	1.25	1.09	....

THE PROBABLE GROWTH OF THE MARKET.

As nearly as we have been able to determine, the average growth of the electric output of the United States is about ten per cent per annum, and we believe a similar growth may fairly be estimated for South Dakota if the proposed water power development is installed.

Power from the Missouri River in South Dakota.

Under normal conditions of growth, we would estimate a slower development in the power output of South Dakota, but it is the general experience that the introduction of cheap power stimulates growth as would normally be expected. As examples it may be stated that the output of the Wisconsin Public Service Company, operating in the territory adjoining Green Bay, Wisconsin, has since 1911 had an average growth of about twenty percent. per annum. The Peninsular Power Company, operating in the territory adjoining Iron Mountain and Iron River, Michigan, has had an average growth of about twenty-two percent. since 1914, and the Commonwealth-Edison Company of Chicago has had an average growth of nearly twenty-six percent. since 1898 (see Figure 11). These plants are all in more thickly populated territories than that of South Dakota and have better market conditions. These rates of growth, however, seem to warrant the lower estimate we have made for South Da-

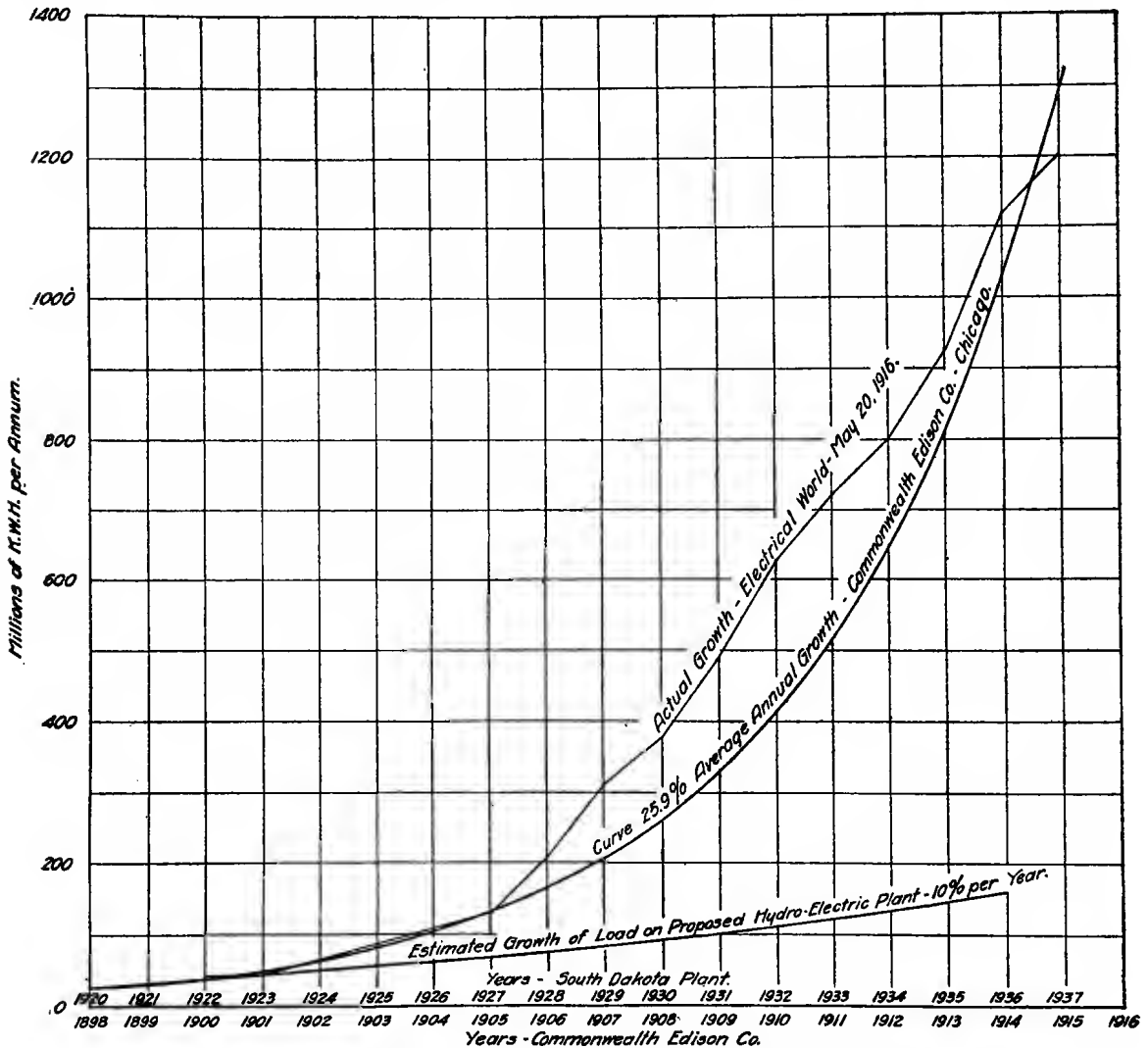


FIGURE 11. Showing Estimated Growth of Power Load in South Dakota compared with Actual Growth of Load of Commonwealth Edison Company of Chicago.

kota. The growth we have estimated for the territory to be served by the proposed Mobridge plant is shown graphically in Figure 11 in which is also shown for comparison the growth of the Commonwealth-Edison Company of Chicago from 1898 to 1915. The prospective growth of the Mobridge output is started with the 30,000,000 kilowatt hours per annum which we estimated might have been secured if the plant had been ready for operation in 1919.

MARKET WHICH WOULD PROBABLY BE AVAILABLE AT THE TIME THE PLANT
COULD BE READY FOR OPERATION.

If the proposed plant is constructed, it would probably be the year 1925 before the plant and transmission system could be completed ready to deliver electrical energy. If the market can be developed simultaneously with the plant it will furnish a greater load than the 30,000,000 kilowatt hours per annum estimated, and the probable load at various dates, and the effect of such load on the cost of power, is shown in Table 7.

TABLE 7.

*Estimated Cost of Power From the Mobridge Plant at Various Periods of
Growth and Under Various Conditions.*

YEAR.	Load Requirements Growth 10% per Annum.	Cost per KILOWATT HOUR, including:			
		Plant and Full Transmission System With Interest, De- preciation and Operating Ex- penses.	Plant and Transmission System with Interest and Operating Ex- pense (Depre- ciation omit- ted.)	Plant and High Voltage Trans- mission (Sec- ondary Trans- mission omit- ted) With In- terest, Depre- ciation and Op- erating Ex- pense.	Plant and High Voltage Trans- mission (Sec- ondary Trans- mission omit- ted) With In- terest and Op- erating Ex- pense (Depre- ciation omit- ted.)
	K.W.H. per year	Cents	Cents	Cents	Cents
1919	30,000,000	4.70	3.23	3.90	2.79
1920	33,000,000	4.28	2.94	3.55	2.54
1921	36,300,000	3.89	2.67	3.23	2.31
1922	39,930,000	3.53	2.43	2.94	2.10
1923	43,923,000	3.21	2.21	2.67	1.91
1924	48,315,300	2.92	2.00	2.42	1.73
1925	53,146,830	2.65	1.82	2.20	1.57
1926	58,461,513	2.41	1.66	2.00	1.43
1927	64,307,664	2.19	1.51	1.82	1.30
1928	70,738,430	2.00	1.37	1.66	1.18
1929	77,812,273	1.81	1.24	1.51	1.07
1930	85,593,500	1.65	1.13	1.37	0.98

PRESENT COST OF POWER FROM FUEL IN SOUTH DAKOTA.

Our investigation of the amount of power used in the State also included an approximate determination of the unit cost of power at the various plants visited.

In general the information available was incomplete and not entirely satisfactory, but it is believed to be sufficient to afford a basis for estimating the price at which power could probably be sold from a hydro-electric system.

Power costs must ordinarily include both fixed charges and operating expenses but when power is to be sold to plants in actual operation, it must be remembered that the fixed charges have been incurred, and therefore the only price which will be attractive is one which effects a saving on the actual operating costs. Power from a hydro-electric plant must therefore be sold at a rate low enough to at least meet, and generally must fall below, operating costs, both in the instance of replacement and as a rule even when extensive increases in the power output are to be furnished. This condition is due to the fact that the contingencies of long distance transmission are such that when constant power must be maintained, the original fuel using power plant not only must be maintained but also must be augmented, with the increased demand for power, in order to maintain an auxiliary reserve that can be used during the temporary interruption to the transmitted current which is certain to occur.

Table 8 gives the best information we were able to obtain concerning fuel costs and total station charges at various fuel using power plants in South Dakota. As the information obtained was in many cases confidential, we are not at liberty to give the names and locations of the various plants represented but the information given contains sufficient data to afford a good foundation for estimates of general power costs in South Dakota.

From Table 8 it will be noted that fuel costs at various plants will run from as low as one cent to over five cents per kilowatt hour and the total station costs from about 1.7 cents to as high as ten cents per kilowatt hour.

THE PROBABLE SELLING PRICE FOR HYDRO-ELECTRIC POWER.

In connection with the discussion of cost of power, it is also desirable to consider the probable price at which current can be sold. It is assumed that the state will supply wholesale power to the several municipalities and power users, and that a price will be charged which will not only pay fixed and operating charges but will refund any deferred interest and depreciation costs which may remain unearned during the first years of operation and ultimately refund the original cost of development or accumulate a fund for further hydro-electric development. There are several factors which enter into the determination of the prices which the customer should pay and the state receive for hydro-electric energy in case the project is undertaken. Among these, load factor and quantity of current used by the consumer are of most importance. We have prepared a set of curves, Figure 12 which are merely tentative and suggestive of an equitable basis for wholesale rates.

Considering the matter of price from the viewpoint of the desirability of a rapid development of a market and the early industrial development of the state, it would seem advisable to make the average selling price as low as financial expedi-

TABLE 8
Summary of Fuel and Station Costs in South Dakota Cities East of the Missouri River. Surveyed July 2 and August, 1919.

No.	Service	Source of Power	Total Machine Capacity	Load Conditions	Cost of Fuel per K. W. H.	Total Station Costs per K. W. H.	Remarks.
1	Water and Electric	Oil	720 K. V. A.		\$.010*	\$.0174	Fuel, labor, insurance and supplies \$.0153 in 1918, .0174 in 1919. Oil 5c per gal. Coal \$6.18 per ton. Maximum fuel rate 5 lbs. per K. W. H.
2	Electric	Steam	2800 K. W.		.0125—.015*		Steam Cost 60c per 1000 lbs. Total operating cost includes fuel, labor, supplies and repairs.
3	Industrial	Steam		Peak-300 K. W.	.015*		
4	Electric	Producer Gas.	725 h. p.	1,020,000 K. W. H. year	.0115	.0189	Coal \$10.50 to \$11.50 per ton. Coal \$10.50 to \$11.50 per ton. Total operating cost includes fuel, labor, supplies and repairs.
5	Water and Electric	Oil	240 K. V. A.	700,000 K. W. H. year	.010	.045 to .05	Power costs estimated by plant supt. Oil 5c per gal. Coal \$11.25 per ton. Ave. coal rate 2.98 lbs. per K. W. H.
6	Electric	Oil and Gas.	197 K. V. A.	3,400 K. W. H. week	.0168*		Coal \$7.90 per ton.
7	Electric	Steam	100 K. V. A.	12,700 K. W. H. month	.075*		Coal \$7.08 per ton.
8	Water	Steam	500 h. p.	14 mill. gals. month	.0312*		Power costs include fuel and labor only, furnished by superintendent.
9	Electric	Oil	300 h. p.	107,000 K. W. H. month		.018 .022	
10	Water and Electric	Steam	100 K. V. A.	12,000 K. W. H. month	.0168*		Coal consumption about 7.5 lbs. per K. W. H. Coal \$4.33 per ton.
11	Electric	Steam	425 K. V. A.	1,200 K. W. H. day	.0167*		Cost from charts for coal and oil run from 1.1c to 2.5c per K. W. H. Coal \$11.50 per ton.
12	Water and Electric	Producer Gas.	100 K. V. A.	Peak 70 to 75 K. W.	.0175		Total cost stated by supt. includes overhead, interest, tax, depreciation and operation.
13	Electric	Steam	310 K. V. A.	1,300 K. W. H. day	.032*	.05 to .055	Cost stated by supt. Coal \$8.15 per ton. F. O. B. Duluth.
14	Electric	Producer Gas.	125 K. V. A.	11,000 K. W. H. month	.0145	.05+	
15	Water	Gasoline	42 h. p.	Pumping	.048*		Coal \$8.60 per ton.
16	Water	Steam	Pumps	189 mill. gals. year	.0548	.107	Cost estimated by supt. Coal \$6.50 per ton. Coal \$7.40 per ton. Supt. stated boiler evaporation is 6 or 8 lbs. per lb. coal. Plant also furnishes steam heating to 35000 sq. ft. radiation. Test in 1914 shows total cost 5c per K. W. H.
17	Electric	Steam	175 K. W.			.05	Non condensing steam pumps. Coal \$7.60. Cost stated by manager.
18	Electric	Steam	350 K. V. A.	Peak 180 K. W.	.02*		Coal \$7.70 per ton. Furnish steam for 40,000 sq. ft. radiation. Cost includes labor, fuel and supplies.
19	Water	Steam	Pumps	1.5 mill. cu. ft. month	.065 to .07	0.20	Cost stated by manager.
20	Industrial	Steam	500 h. p.			0.02	Cost stated by manager. Includes labor, fuel and supplies only. Coal \$5.75 per ton, Oil, 7c per gal.
21	Electric	Steam	375 K. V. A.	Peak 200 K. W.		.06	Cost stated by manager. Oil 7 1/4c per gal. Coal \$4.34 per ton. Coal consumption stated about 5 lbs. per K. W. H.
22	Industrial	Steam	80 h. p.	1,200 K. W. H. per day	.019	.04	Coal \$8.00 per ton. Records show 8 lbs. coal per K. W. H.
23	Electric	Oil and Steam	230 K. V. A.				Coal rate 3.5 to 3.75 lbs. per H. P. Coal \$7.00 per ton. Oil 7c per gal. Coal \$12.00 per ton.
24	Electric	Oil	75 K. W.	Peak 300 amp. 22 ov.	.0275		
25	Electric	Steam	1840 K. V. A.	2.4 mill. K. W. H. year	.0108*		
26	Water and Electric	Steam	200 K. W.	650 K. W. H. day	.032*		
27	Industrial	Steam	262 K. V. A.	25,000 K. W. H. months	.02*		
28	Electric	Oil and Steam	260 K. V. A.	1,000 K. W. H. day	.034*		
29	Electric	Producer Gas.			.015*		

*Computed in office of Mead & Seastone from data secured at the plant.

ency will permit. For purposes of this report we have assumed an average selling price of about 1.87 cents per kilowatt hour. This would correspond to an average load of about 175 kilowatts at a 33½ percent. load factor. A customer using a small amount of power at a low load factor, say an average load of twenty kilowatts at twenty percent. load factor would, on the basis of these tentative price curves, pay a wholesale rate to the State of three cents per kilowatt hour; whereas a large customer, using 1,000 kilowatts on a sixty percent. load factor, would pay a rate of 1.25 cents per kilowatt hour.

COST OF DEVELOPING A MARKET.

Should the total output of the plant be limited to 30,000,000 kilowatt hours per year, the resulting income on the basis of an average selling price of 1.87 cents per kilowatt hour would be insufficient to pay interest and operating expenses. This deficit would amount to \$407,500 for the first year. With a ten percent. annual growth in the market the deficit would decrease each year until when the sale of power reached an annual amount of 53,000,000 kilowatt hours, the loss would cease and thereafter a profit, above interest and operating charges, would result. Table 9

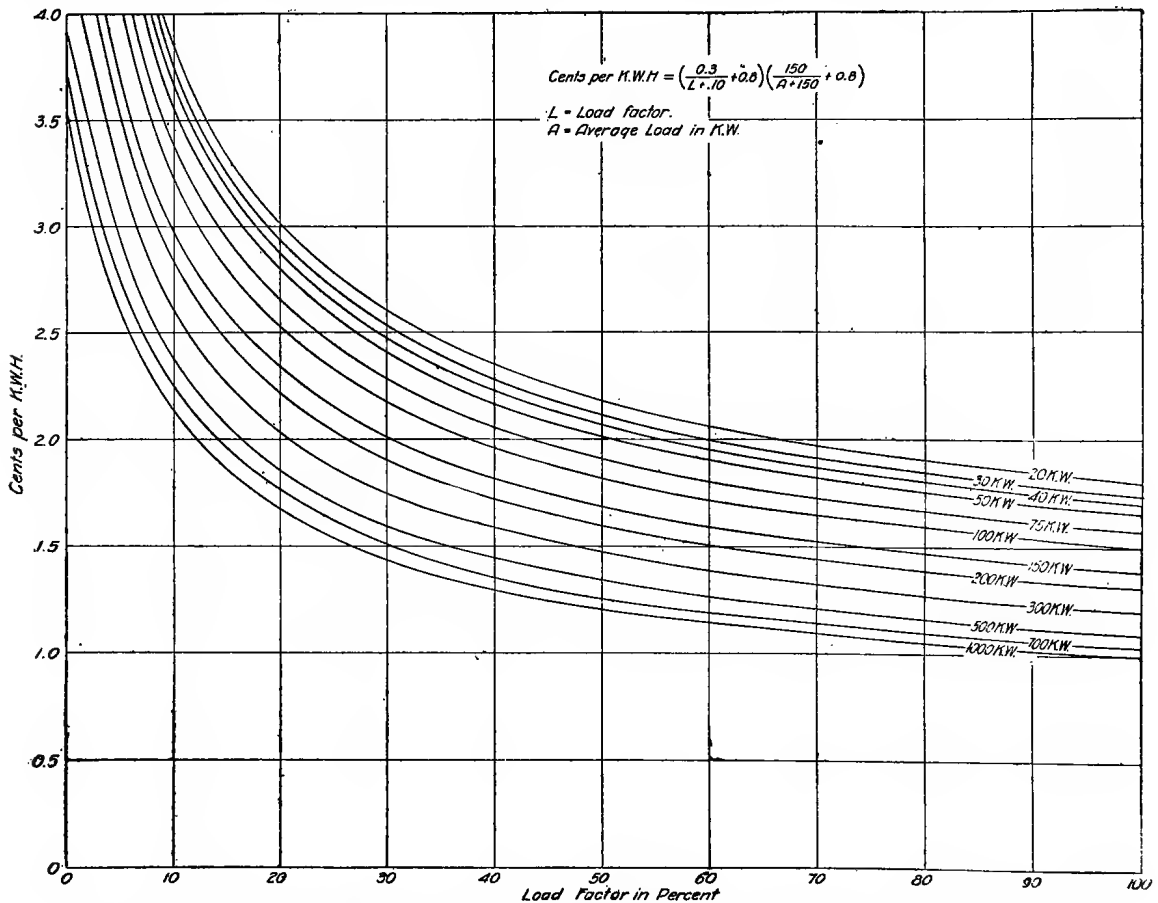


FIGURE 12. Showing Tentative Curves of Rates at which Power may be sold to Municipal and Private Companies in South Dakota.

shows in detail the estimated annual loss and gain (from interest and operation costs) with the ten percent annual growth estimated. From this table it will be noted that, if the plant had started with an annual output of 30,000,000 kilowatt hours in 1919 and the output increased uniformly at a ten percent. annual rate, it is estimated that by 1924 the total loss (not considering interest on the deficits) would have amounted to \$1,486,400. This amount is the cost of developing the market and is part of what is ordinarily termed development expense. This is commonly represented by lost dividends in a privately owned plant and increases until the earnings reach a normal dividend paying basis.

TABLE 9.

Development Expense based on possible interest losses during early years of operation, including cost of entire plant with primary and secondary transmission systems.

Year.	Output K. W. H.	Cost of Power Cents	Average Sale Price Cents	Difference of Cost and Sale Price Cents	Loss	Profit	Accumulat- ed Loss In- cluding 5 Percent Interest Charge.	Accumulat- ed Profit Including 5 Percent. Interest Charge.
1919 --	30,000,000	3.23	1.87	—1.36	\$ 407,500	\$-----	\$ 407,500	\$-----
1920 --	33,000,000	2.94	1.87	—1.07	353,000	-----	780,875	-----
1921 --	36,300,000	2.67	1.87	—0.80	290,500	-----	1,110,419	-----
1922 --	39,930,000	2.43	1.87	—0.56	223,500	-----	1,389,440	-----
1923 --	43,923,000	2.21	1.87	—0.34	149,000	-----	1,607,912	-----
1924 --	48,315,300	2.00	1.87	—0.13	62,900	-----	1,751,207	-----
1925 --	53,146,830	1.82	1.87	+0.05	-----	26,600	1,812,168	-----
1926 --	58,461,513	1.66	1.87	+0.21	-----	122,799	1,780,075	-----
1927 --	64,307,664	1.51	1.87	+0.36	-----	231,500	1,637,580	-----
1928 --	70,738,430	1.37	1.87	+0.50	-----	353,500	1,365,959	-----
1929 --	77,812,273	1.24	1.87	+0.63	-----	491,000	943,257	-----
1930 --	85,593,500	1.13	1.87	+0.74	-----	634,000	356,420	-----
1931 --	87,600,000	1.10	1.87	+0.77	-----	675,000	-----	\$300,759*
Total -----					\$1,486,400	\$2,534,300		
Loss without interest -----						1,486,400		
Profit without interest -----						\$1,047,900		

*Profit including interest on early losses.

In the case of the state plant, a profit (above interest and operating expenses) is shown for the year 1925 which increases annually until the capacity of the plant is reached in 1931, after which the annual profit would remain essentially stationary unless the sale price is changed.

Considering the entire thirteen years represented in the table, the gain (over interest and operating expenses) exceeds the losses by about \$1,048,000, although if interest on the deficits be considered this amount would be reduced to about \$300,000. This would be increased thereafter at the rate of about \$675,000 per annum until a normal depreciation fund is established after which the earnings could be applied to the liquidation of the capital cost or to further extensions.

TABLE 10.

Development expense based on possible interest losses during early years of operation including cost of plant and main transmission system, secondary transmission system eliminated.

Year.	Output K. W. H.	Cost of Power Cents	Average Sale Price Cents	Difference of Cost and Sale Price Cents	Loss	Profit	Accumulat- ed Loss In- cluding 5 Percent Interest Charge	Accumulat- ed Profit Including 5 Percent. Interest Charge
1919 --	30,000,000	2.79	1.67	—1.12	\$ 336,000	\$-----	\$ 336,000	-----
1920 --	33,000,000	2.54	1.67	—0.87	287,000	-----	639,800	-----
1921 --	36,300,000	2.31	1.67	—0.64	232,000	-----	903,790	-----
1922 --	39,930,000	2.10	1.67	—0.43	171,500	-----	1,120,479	-----
1923 --	43,923,000	1.91	1.67	—0.24	105,200	-----	1,281,703	-----
1924 --	48,315,300	1.73	1.67	—0.06	29,000	-----	1,374,789	-----
1925 --	53,146,830	1.57	1.67	+0.10	-----	53,200	1,390,328	-----
1926 --	58,461,513	1.43	1.67	+0.24	-----	140,000	1,319,844	-----
1927 --	64,307,664	1.30	1.67	+0.37	-----	238,000	1,147,837	-----
1928 --	70,738,430	1.18	1.67	+0.49	-----	346,000	859,229	-----
1929 --	77,812,273	1.07	1.67	+0.60	-----	446,000	436,190	-----
1930 --	85,593,500	0.98	1.67	+0.69	-----	591,000	-----	133,000
1931 --	87,600,000	0.95	1.67	+0.72	-----	631,000	-----	770,650*
Total -----					\$1,160,700	\$2,465,200		
Loss without interest -----						1,160,700		
Profit without interest -----						\$1,304,500		

*Profit including interest charges on early losses.

A further examination of this table will show that if the market can be developed, so that the demand at the time of completion of the plant will reach 53,000,000 kilowatt hours per annum, the income received will be sufficient to meet interest and operating expenses and would be sufficient by 1929 to meet annual depreciation charges as well.

Table 10 shows the same calculation made on the basis of the elimination of the secondary transmission lines. Under these conditions the average selling price for power is estimated at 1.67 cents per kilowatt hour in order to compensate power users for the cost of constructing secondary transmission systems. In this case, considering interest on the deficits, a balance (above interest and operating expenses) of about \$770,000 would remain at the end of 1931.

It is obvious that the actual condition of development will vary more or less from the estimates shown in these tables. If the growth is less rapid the development expense will increase and the recovery will be slower, while if the growth be more rapid the development expense will be reduced and the recovery will occur earlier.

The rate of growth of the power market may seriously affect the cost of development and stagnation in development, due to the inability of the state to effect sufficient sales of power, to financial panics, or other causes, might involve a continuing loss for some years. This is a risk which the development of such a project naturally entails and which cannot be obviated.

It is therefore evident that the success of the contemplated development depends not only on the original cost of installation but also on the growth and development of a power market in South Dakota.

It should be noted that the estimated cost of the development on the basis of construction costs in 1919-20 is approximately sixty-seven percent. greater than it would have been in 1914; that the present financial situation is unstable and undoubtedly inflated; that the present prices that have heretofore been increasing may be at a peak; and that the present situation in regard to labor, materials, and capital is not favorable to such enterprises. The advisability of undertaking the development at this time becomes a serious question, the final decision of which must be left to your Honorable Body and to the Legislature who are responsible to the electors of the State.

APPENDIX I.

POWER MARKET IN SOUTH DAKOTA.

Up to the present time the use of power in South Dakota has been confined principally to supply its cities and towns with light and water, for minor power purposes and for such limited cooking and heating uses as are common in such communities. Power is generated and used by several milling companies and for a number of mines and quarries but manufacturing as such is confined to a few industrial establishments in the larger cities which purchase small amounts of power from the local electric companies.

PROBABLE INDUSTRIAL DEVELOPMENT.

It is not likely that extensive industrial development can be expected to take place in South Dakota in the early future but with the growth of population certain local demands for manufactured products may reasonably be expected to be met to greater advantage by local manufacturing. A good grade of Portland Cement was previously manufactured at or near Yankton but the factory has been shut down and cement is now shipped in from outside the state. The raw materials available are, we understand, well suited to the manufacture of Portland cement and with the increase in demand a good market should be available for the proposed state cement plant for the construction of buildings, sidewalks, pavements, and roads. With cheap cement a market should readily be found for the product of a plant manufacturing concrete building blocks, fence posts, concrete electric poles, street lighting posts, etc.

Those familiar with the resources of the state may find numerous purposes which local demands will create when cheap power is available.

THE MARKET FOR HYDRO-ELECTRIC POWER.

By far the greater part of the power used in the state east of the Missouri River is developed from fuel and as most of the plants are small the cost of power is high and constantly increasing with the increasing prices of coal and fuel oils. The location of communities of 300 or more (according to the 1910 census) where the market for power must be found, is shown in Figure 1, page 11, on which the relative population of each city or town is approximately indicated by the size of the circle.

An examination of this map, together with our estimate of the cost of transmission system (See Table 2, page 35, also appendix 4) will show conclusively, that it is financially impossible at the present time to reach all of the communities of the state, but that in order to render an hydro-electric development at all practicable the

transmission system must be limited to such lines as are necessary to reach the more thickly settled portions of the state east of the Missouri River, leaving the other sections of the state to be served when the local power markets are so developed as to make such lines financially practicable.

EXTENT OF EXAMINATION OF POWER MARKET.

For the reasons previously discussed and in order to avoid useless expense in the investigation made to determine the feasibility of this project our examination of the market has been confined to the principal communities east of the Missouri River. For the purpose of this report thirty-five of the principal communities in this area were visited and the available data, so far as possible, bearing on the cost of power and the probable price at which power might be sold to these communities were collected.

DATA AVAILABLE.

In many of the plants no means of measuring the power outputs of the plants were available and records from which the cost of power could be accurately determined were missing. In most cases some data giving fuel used and power output for limited periods, were available, while in a few cases the data available were more complete and satisfactory.

In most cases all data apparently available were cheerfully furnished and the lack of data was due to the faulty system of records kept at the power plants. In some cases not only was all data refused but our representative was not allowed to visit the power plants. This may have been due to the absence of responsible officials, and to the location of the main office at points outside of the state.

SAVING EFFECTED BY THE USE OF HYDRO-ELECTRIC POWER.

The cost of power to the owner of any power plant will include, interest on the money invested in the power plant, depreciation on the plant and equipment, and the cost of operation which will include the costs of fuel, lubricants, supplies, maintenance, and labor.

In considering, however, the saving which can be made to the owner of such a plant by the substitution of hydro-electric power it must be remembered that the investment for the power plant has been entailed and that interest and depreciation therefore cannot be eliminated. Hydro-electric power in order to be attractive must be sold, therefore, at a price which will be below station costs and in some cases even as low as fuel costs.

This is also true when hydro-electric power is sold to new customers who have no investment in power plants, but who must maintain continuous service. In such cases auxiliary plants must be established and maintained at all times in order to be ready for the contingencies of interrupted service which is certain to occur where power is furnished from a distance over a long transmission system. While such interruptions are only for brief periods, they may prove serious in municipal service

Power from the Missouri River in South Dakota.

and other service where constant and dependable power must be provided. In such cases not only must old power plants be maintained but they must sometimes be augmented by additional installations in order to be able to maintain service under all contingencies.

COST OF POWER EAST OF THE MISSOURI RIVER.

The actual cost of electric power in South Dakota varies considerably with the type and size of plant, the cost of fuel and labor (See Table 8, page 43). In many cases, east of the Missouri River the cost varies from 3 cents to 8 cents per kilowatt hour at the switchboard, the maximum cost reaching as high as 18 cents per kilowatt hour and the minimum perhaps as low as 1.5 cents per kilowatt hour. The low costs are obtained only at the larger and more modern plants.

POSSIBLE SAVINGS FROM USE OF HYDRO-ELECTRIC POWER.

If an average cost of 2.87 cents per kilowatt hour is assumed, which is a fair average at the switchboard for that portion of the current which may be replaced by hydro-electric power, the saving to the power companies, assuming 1.87 cents per

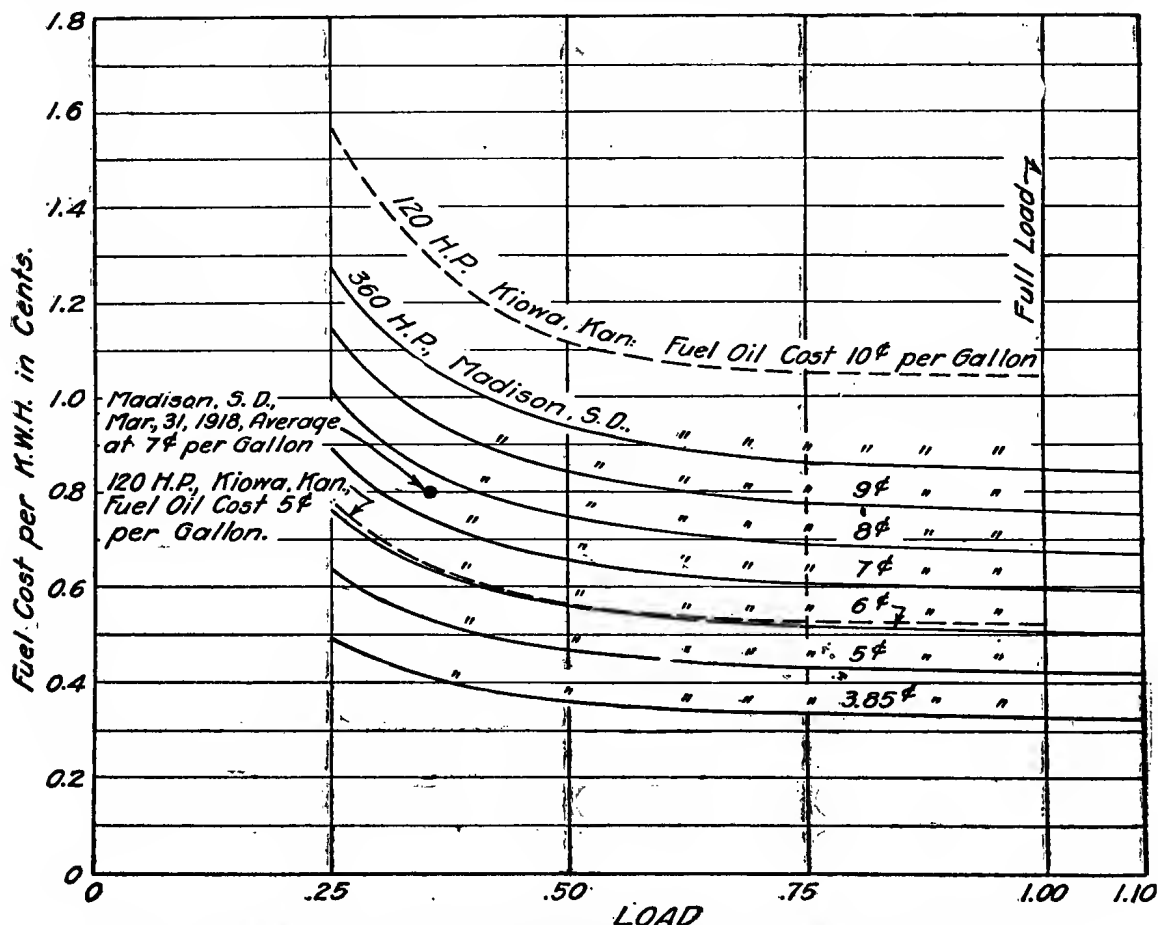


FIGURE 13. Variation in Cost of Power from Fuel Oil with Change in Cost of Oil and at Various Loads.

kilowatt hour as the average cost to the distributing companies, would be one cent per kilowatt hour or, on the basis of an annual output of 55,000,000 kilowatt hours, a total saving of \$550,000 per year, which would increase each year as coal costs increase and as the demand for current increases.

INCREASING COSTS OF POWER FROM FUEL.

With coal costing \$6.00 to \$8.00 per ton delivered, the cost of coal for power in the various plants examined varies from 1.02 cents to 6 cents per kilowatt hour, and the total cost of power at the switchboard varies from 1.5 cents to 18 cents per kilowatt hour. These costs are constantly increasing with the rise in the cost of coal due to increased labor and transportation charges. In the case of plants using oil engines, the fuel cost alone varies from 0.5 cents to 1.5 cents per kilowatt hour, and the total cost at the switchboard at from 1.5 cents to 5 cents depending upon the size of plant, fuel cost and labor cost. Figure 13 shows graphically the cost of power from fuel oil at various prices and with various load factors. This diagram was constructed by plotting the actual test data obtained in 1915 for a 360 HP Diesel engine at Madison, S. D., with fuel oil costing 3.85 cents per gallon. In 1918 fuel oil cost 7 cents to 8 cents per gallon delivered and it is reasonable to expect that with increased use of oil for farm tractors, etc., the cost may reach 10 cents to 12 cents per gallon within a few years. For this size and type of plant, the fuel cost for different conditions of loading and prices of fuel oil may be read directly from the diagram. For smaller plants the cost increases materially. For example, the 120 HP plant at Kiowa, Kansas, with fuel oil at 5 cents per gallon and 10 cents per gallon respectively the cost of power is as shown by the dotted lines on the diagram.

POWER USED IN SOUTH DAKOTA.

East of the Missouri River most of the power now used is generated from coal, oil, or gas although water power has been developed at the following places.

TABLE 11.

Water Power Developed East of the Missouri River.

(Data from Senate Document 316, 64th Congress, 1st Session.)

Consumers Power Co., Sioux Falls, Big Sioux River	2,000 HP
Electric Light and Power Co., Sioux Falls, Sioux River	65 HP
Dell Rapids Light & Power Co., Baltic	150 HP
Flandreau Light & Power Co., Flandreau	75 HP
Total	2,290 HP

Most of the power used west of the Missouri River has been developed in the Black Hill mining region from water power as follows:

Power from the Missouri River in South Dakota.

TABLE 12.

Water Power Developed West of the Missouri River.

Centerville Mining Company, Centerville	50 HP
Consolidated Power & Light Company of S. D., Spearfish—Red Water River	1,000 HP
Dakota Power Company, Rapid City and vicinity	2,400 HP
Dakota Power Company, Rapid City.....	150 HP
Gordelia Mining Company, Rockford.....	10 HP
Homestake Mining Company, Spearfish, Spearfish Creek	6,000 HP
Water, Light and Power Co., Hot Springs, Fall River	450 HP
Spearfish Electric Co., Spearfish, Spearfish Creek	225 HP
Hot Springs Irrigation and Live Stock Co., Cascade Creek	370 HP
Rapid River Milling Co., Rapid City.....	88 HP
Total	10,743 HP

SUMMARY OF POWER USED EAST OF THE MISSOURI RIVER.

The following summary gives the data for communities east of the Missouri River containing approximately a total of 184,500 population. In many cases the yearly output has been estimated from monthly, weekly and daily records and in a few cases is based on cities having similar characteristics. For these reasons some of the estimates of annual outputs may not agree accurately with the actual annual power used, but the total of 38,467,000 kilowatt hours per annum for all the communities listed is believed to be a fairly accurate estimate of the actual power used in 1919 in these places. This includes our estimate of hydro-electric power generated at Sioux Falls and Flandreau. The total power used in 1919 for which hydro-electric power might be substituted must therefore be reduced on this account, also because there are probably other loads that cannot be replaced with hydro-electric energy. Our estimate therefore of the total quantity of power that could have been replaced with hydro-electric energy for the year 1919 is 30,000,000 kilowatt hours.

THE POSSIBLE USE OF HYDRO-ELECTRIC POWER BY THE CHICAGO, MILWAUKEE
& ST. PAUL RAILWAY.

The Chicago, Milwaukee and St. Paul Railway has already introduced the use of electric traction on two sections of their system in the West, and might possibly consider the use of hydro-electric power on their lines in and adjoining the state of South Dakota. A discussion of this matter with the Railroad officials seems to indicate, however, that due to the numerous betterments made necessary by the return of the road to the Company by the United States Railway Administration, such use cannot be considered for at least some years to come. Also that the price which could be paid for power would have to be so low as to make such a market of questionable value to the state at this time.

RECORDS OF POWER PLANTS IN SOUTH DAKOTA EAST OF THE MISSOURI RIVER.

Abbreviations.

H. P.—Horsepower.

H. P. H.—Horsepower Hours.

K. W.—Kilowatt.

K. W. H.—Kilowatt Hours.

K. V. A.—Kilo-Volt-Amperes.

ABERDEEN.*Aberdeen Light and Power Company*

Equipment 4 250 HP Stirling Water Tube Boilers, Steam Pressure 150 lbs.
 2 Cross Compound Corliss Engines, driving:
 2 420 KVA, 3-phase, 60 cycle, 2300 volt Generators.
 Surface Condenser and Hot Well.
 Feedwater Temperature 190° F.
 Superheater Temperature 450°—500° F.

Fuel Roundup Coal, \$4.34 per ton delivered.
 Use about 5 lbs. Coal per Kilowatt Hour.

Peak Load Hourly 650 to 850 KW.

Yearly Output 1913—1,627,000 KWH or 186 KW average load|
 1914—1,634,000 KWH or 187 KW average load.
 1915—1,889,000 KWH or 215 KW average load.
 1916—2,206,000 KWH or 252 KW average load.
 1917—2,249,000 KWH or 257 KW average load.
 1918—2,385,000 KWH or 272 KW average load.

Municipal Sewerage Pumping Station.

Equipment 3 Gas Producers—One 50 HP, one 100 HP, and one 160 HP.
 1 150 HP Munzel Single Cylinder Horizontal Gas Engine.
 1 50 HP Munzel Single Cylinder Horizontal Gas Engine.
 1 8", two 10" and one 12" Centrifugal Pumps, rope driven from shaft.

Operation No Records.

Load Average 1600 to 1800 gallons per minute.
 Peak 4200 gallons per minute.
 Lift 25 to 36 feet.

Municipal Water Works.

Domestic Pressure 75 lbs. direct from Artesian Wells.

Reservoir 750,000 gallons capacity.

Fire Service 3 100 HP Motors, driving centrifugal pumps
 —capacity 1,000 gallons per minute.

Power From Aberdeen Light and Power Company.

Chicago, Milwaukee and St. Paul Railway Shops.

Equipment	4 Internally fired Return Tubular Boilers. 1 Ingersoll Rand Simple Two-Stage Air Compressor. 2 Vertical Westinghouse Automatic Engines--direct connected to: 1 Duplex High Pressure Double Acting Pump.
Fuel	No Coal Records available.
Note:—	Boilers used for both power and heating.

ARMOUR DISTRICT (Including eleven towns.)

South Dakota Light and Power Company.

Equipment	1 300 HP Gas Producer. 1 300 Rathbun-Jones Gas Engine, driving: 1 200 KW 3-phase 60 Cycle, 2300 Volt Generator. 2 250 HP Diesel Oil Engines, driving: 2 175 KW 3-phase 60 Cycle 2300 Volt Generators. 33,500 Volt Transmission Line.
Peak Load	320 KW.
Output	For June 1919, 106,399 KWH.
Retail Rates	Power 4c to 8c per Kilowatt Hour. Lighting 6c to 15c per Kilowatt Hour.
Towns Served	Armour, Wagner, Lake Andes, Geddes, Platte, Scotland, Parkston, Tripp, Ravinia and two others.

ASHTON DISTRICT (Including nine towns.)

Ashton Power Company.

Equipment	1 72"x18" Return Tubular Boiler. 1 Four Valve Fulton Engine, driving: 1 150 KW 3-phase 60 Cycle 2300 Volt Generator. 1 120 HP Diesel Engine, driving: 1 80 KW 3-phase 60 Cycle 2300 Volt Generator.
Fuel	In July 1919, used 160 gallons Crude Oil and 2 tons of Illinois Screen Coal per 24 hours. Coal costs—\$1.85 at mines or \$5.75 delivered. Crude Oil, 7c per gallon delivered.
Peak Load	150 Kilowatts.
Output	About 1200 KWH per day.
Towns Served	Mellette, Northville, Ashton, Doland, Raymond, Frankfort, Conde, Brentford, Athol.

BRADLEY DISTRICT (Including nine towns.)

Dakota Northern Company.

Equipment	1 125 HP Return Tubular Boiler, Steam Pressure 120 lbs. 1 150 HP Return Tubular Boiler, Steam Pressure 120 lbs. 1 150 HP Corliss Engine, belted to:
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	1 150 KVA 3-phase 60 Cycle 2300 Volt Generator.
	1 Diesel Engine, direct connected to
	1 112KVA 3-phase 60 Cycle 2300 Volt Generator.
Fuel	Roundup Coal—Costs \$7 per ton in bin. Fuel Oil 7c per gallon in tank.
	At Bradley and Groton 70 gallons of Fuel Oil are used per day.
Load	Average of 16 months 25,000 KWH per month.
Operation	Diesel Engine runs about 8 hours per day.
Service	About 4,000 population in 9 towns.

BROOKINGS.

Municipal Electric Lighting Plant.

Equipment	5 80 HP 60"x16' Return Tubular Boilers, Steam Pressure 90 to 120 lbs.
	1 Simple Non-Condensing Corliss Engine, belted to:
	1 150 KW 2-phase 60 Cycle 2300 Volt Generator.
	1 Four Valve Non-condensing Ball Engine, directed connected to
	1 200 KW 2-phase 60 Cycle 2300 Volt Generator.
Fuel	15 to 16 tons of Coal used per day in Winter and 6 to 8 tons per day in Summer. Costs \$7.40 per ton delivered.
	Steam used in Heating 35,000 sq. ft. of Radiators.
	No means of separating Heat and Power Loads.
	Evaporation 6 to 8 lbs. per pound of Coal.
Peak Load	In Winter 180 KW. On July 25, 1919, at 4 P. M. load 55 KW.
Output	Average 45,000 KWH per month for 5 months.
Power Cost	Test on Plant 5 years ago showed 5c per KWH at switchboard.

CANTON (Including three towns.)

Sioux Valley Power Company.

	2 150 HP Return Tubular Boilers, Steam Pressure 135 lbs.
	1 125 HP Return Tubular Boiler, Steam Pressure 135 lbs.
	1 275 HP Simple Corliss Engine.
	1 150 KW 3-phase 60 Cycle 2300 Volt Generator.
	1 75 HP Simple Corliss Engine.
	1 60 KW 3-phase 60 Cycle 2300 Volt Generator.
	1 120 HP Ideal Engine.
	1 100 KW 3-phase 60 Cycle 2300 Volt Generator.
Fuel	Use an average of 7 to 8 tons of Coal per Day, not over 200 tons per Month.
Peak Load	Winter 360 KW, Summer 300 KW.
Daily Load	In May, 1380 KWH per Day.
Load Factor	Summer 19¼%, Winter 16%.
Towns Served	Canton, Inwood, Fairview.

CHAMBERLAIN (AND OCOMA.)

Peoples Gas and Light Company.

Equipment	1 100 HP Meitz and Weiss Oil Engine, belted to: 1 75 KW Alternating Generator. 1 50 HP Meitz and Weiss Oil Engine, belted to: 1 37.5 KW Alternating Generator.
Operation	Day Service only (34.5 HP motors.)
Service	Bottling Works, Columbus College (10 HP motor), 3 Garages with two 5 HP Motors each.
Records	300 Residences on Meters and 3 Hotels. No Meters at Plant, no records available.
Price	Retail Price for Lighting Current 20c per Kilowatt Hour.

DELL RAPIDS.

Municipal Water and Gas Plant.

Equipment	1 40 HP Return Tubular Boiler. 1 60 HP Return Tubular Boiler. 1 10 HP Engine and Centrifugal Blower. 1 8"x12" Air Compressor. 1 8"x10"x8" Gas Compressor. 1 8.5" & 12"x8.5"x10" Tandem Compound Non-condensing Gordon Pump. 1 12"x8"x10" Simple Duplex Pump.
Fuel	1.9 Tons Coal per Day. Water Gas Machine uses .5 ton Coke and 80 gallons Gas Oil per Day.
Service	No method of proportioning coal between water and gas services 215 House Meters and 160 Flat Rate Connections.
Operation	Air Lift used on wells only when water is below reach of pump suction.

Stone Quarry.

Equipment	1 60 HP Return Tubular Boiler. 1 35 HP Simple Engine, operating: 1 No. 5 Crusher.
Fuel	For year 1916 used 300 tons of Youghiogheny coal. Cost about \$5 per ton delivered.
Operation	Crushed 24,394 cu. yds. of stone in addition to operating hoist, pumping water, etc. Run 10 hours per day.

ELK POINT.

Municipal Electric Light Plant.

Equipment	1 No. 72 Gas Producer.
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	1 No. 60 Gas Producer.
	2 Foos Vertical 3 Cylinder Gas Engine.
	2 50 KW Ft. Wayne 3-phase 60 Cycle 2300 Volt Generators.
Fuel	Buckwheat Anthracite Coal, Cost \$11.50 per ton in bin. Average for March, 3 lbs. coal per KWH.
Peak Load	February, 70 to 75 KW, June, 55 to 60 KW.
Sale Price	Heating current retails for 6c per KWH. Lighting 9c to 20c. Power 8c to 16c. Minimum bill, \$1.25 per month. 10% discount for prompt payment.
Power Cost	Average about 2.25c per KWH at Switchboard, exclusive of labor.
NOTE:—Railroad pumps its own water with gasoline engine.	

FLANDREAU DISTRICT.

Dakota Light and Power Company.

Equipment	4 Smith Gas Producers, Total 925 HP. 1 20"x20" Rathbun Jones Gas Engine, connected to: 1 200 KW 3-phase 60 Cycle 2300 Volt Generator. 1 12.75"x13" Rathbun Jones Gas Engine, connected to: 1 75 KW 3-phase 60 Cycle 2300 Volt Generator. 1 12.75"x15" Rathbun Jones Gas Engine, connected to: 1 60 KW 3-phase 60 Cycle 2300 Volt Generator. 1 16"x16" Rathbun Jones Gas Engine, connected to: 1 150 KVA 3-phase 60 Cycle 2300 Volt Generator.
Fuel	85 Tons Anthracite Coal per Month. Cost \$10.20 per ton, 2 lbs. Coal per KWH at Switchboard.
Peak	350 KW.
Retail Rates	Lighting 9c to 15c per KWH, Power 4c to 8c per KWH. Cooking 4c per KWH.
Yearly Output	For 1919, 1,019,340 KWH.
Towns Served	Flandreau, Colman, Wentworth, Elkton, Bushnell, Egan, Trent, Ward, Aurora, White, S. D., and Verdi, Lake Benton, Minn.

Municipal Water Works.

Equipment	1 Motor Driven Power Pump, 85 gallons per minute. 1 Motor Driven Power Pump, 50 gallons per minute. 1 Motor Driven Centrifugal Pump, 300 gallons per minute. 2 60 HP Return Tubular Boilers. 1 10" & 16"x9"x12" Tandem Compound Duplex Pump Exhaust to Closed Heater.
Fuel	Illinois Coal costs \$8 per Ton delivered.
Operation	Ordinary Water Pressure 60 lbs. Fire Pressure 125 lbs. Pump water for Indian School.

Power from the Missouri River in South Dakota.

Power Cost Current purchased from Dakota Light and Power Company at 4c per KWH in summer.

GROTON.

Dakota Northern Company.

Equipment 1 70 HP Munzel Oil Engine, connected to:
 1 75 KW Direct current 220 Volt Generator.
 1 30 HP Munzel Oil Engine, connected to:
 1 50 KW Direct current 220 Volt Generator.
 Operation See Bradley Note.

HURON.

Huron Light and Power Company.

Equipment 2 175 HP Return Tubular Boilers.
 1 Diesel Engine, connected to:
 1 266 KW 3-phase 60 Cycle 2300 Volt Generator.
 1 Horizontal Munzel Gas Engine, connected to:
 1 200 KW 3-phase 60 Cycle 2300 Volt Generator.
 1 Horizontal Munzel Gas Engine, connected to:
 1 100 KW 3-phase 60 Cycle 2300 Volt Generator.
 1 16"x36" Simple Condensing Corliss Engine, belted to:
 1 300 KW 3-phase 60 Cycle 2300 Volt Generator.
 1 Non-condensing Ball Engine, connected to:
 1 180 KW 3-phase 60 Cycle 2300 Volt Generator.
 Operation Larger part of current produced by Oil Engine and Generator.

Municipal Water Works.

 2 100 HP Return Tubular Boilers, Steam Pressure 150 lbs.
 1 14" & 28"x9.5"x24" Crank and Flywheel Corliss Pumping Engine, Capacity two million gallons per day.
 1 Duplex Pump as reserve. Capacity one million gallons per day.
 1 Pittsburg Rapid Sand Filter. Capacity one and one-half million gallons per day.
 1 6" Low Lift Centrifugal Pump, driven by:
 1 35 HP Motor.
 Fuel Use 80 tons coal per month. Cost \$8.50 in bins.
 Cost of Fuel only \$6,734.02 or 4.08c per HPH.
 Operation 9 hours per day, approximately 700,000 gallons per day.
 Output For year ending September 1, 1918, 188,988,360 gallons pumped at total operating cost of \$13,197.32, or about 8c per HPH.

LAKE PRESTON DISTRICT (Including four towns.)

Central Light and Power Company.

Equipment 2 175 HP Return Tubular Boilers.

	1 90 HP Return Tubular Boiler, Steam Pressure 125 lbs.
	1 Simple Non-condensing Murray Corliss Engine.
	1 100 KW 3-phase 60 Cycle 2300 Volt Generator.
	1 Simple Non-condensing Twin City Corliss Engine.
	1 75 KW 3-phase 60 Cycle 2300 Volt Generator.
Fuel	Montana Coal costs \$6.56 in bin.
	North Dakota Coal costs \$4.10 in bin.
Operation	No output meters at station.
Towns served	Desmet, Hetland, Lake Preston, Irwin.

MADISON.

Municipal Electric Light and Water Works.

Equipment	1 360 HP Diesel Engine, connected to:
	1 240 KW 3-phase 60 Cycle 2300 Volt Generator.
	1 11"x12" Deane Triplex Pump, driven by chain belt from electric Motor.
	1 9.5"x10" Deane Triplex Pump, geared to motor.
Fuel	Oklahoma Oil, 6c per gallon in 1919.
Peak	300 KW.
Output	700,000 KWH per year.
Power Cost	Fuel and Labor 1.86c per KWH.
Load Factor	About 27%.

MILBANK.

Milbank Light and Power Company.

Equipment	2 100 HP Gas Producers.
	1 200 HP Gas Producer.
	1 150 HP Gas Engine, direct connected to:
	1 150 KVA 2-phase 60 Cycle 2300 Volt Generator.
	1 100 HP Munzel Gas Engine, directed connected to:
	1 60 KVA 2-phase 60 Cycle 2300 Volt Generator.
	1 90 HP Munzel Gas Engine, direct connected to:
	1 50 KVA 2-phase 60 Cycle 2300 Volt Generator.
Operation	1070 KWH generated from 2760 lbs. coal and 3 gallons oil in one day.
Labor	Manager and three one-man shifts.
Service	536 Consumers.

Milling Company.

Equipment	1 60 HP Return Tubular Boiler. Installed in 1906.
	1 60 HP Tandem Compound Buckeye Engine.
Operation	Capacity of Mill about 250 bbls. per 24 hours. Run about 80 bbls. in 10 hours. Last year's operation low and intermittent. Coal high cost and poor quality. No further data available.

MITCHELL.

Mitchell Power Company.

Equipment	Boiler Plant—No data. 1 500 HP Diesel Engine. 2 225 HP Diesel Engines. 1 400 HP Simple Non-condensing Corliss Engine.
Fuel	Oil Cost, 6.5c per gallon. Coal Cost, \$7 per ton.
Peak	575 KW.
Operation	Have 350 HP Motor Load.
Output	About 150,000 KWH per month.

Municipal Water Works.

Equipment	1 100 HP Return Tubular Boiler. 1 75 HP Scotch Marine Boiler, Steam Pressure 125 lbs. 1 Crank and Flywheel Cross Compound Pumping Engine. Capacity two million gallons per day. Water Pressure 74 lbs. 1 Ingersoll-Rand Cross Compound Air Compressor for Emergency Air Lift. 1 American Well Works Deep Well Centrifugal Pump.
Fuel	45 Tons of coal per month. Cost \$7.08 per ton in shed.
Operation	14 Million Gallons Pumped per Month. About 8.8 lbs. Coal per HPH.

Note.—New Plant under Construction.

MOBRIDGE.

The Mobridge Electric Company.

Equipment	Boiler Plant no Data Furnished. 1 160 HP Murray Corliss Engine. 1 300 HP Murray Corliss Engine. 1 G. E. Generator Type ATB 90 KW @ 80% PF. 1 G. E. Generator Type ATB 180 @ 80% PF.
Fuel	Average 700 Tons Coal per Month. Haynes Lignite Lump, Lignite Screenings, Star Coal Screenings and Roundup Screenings.
Operation	Operate Steam Heating System 8 months in year.
Output	50,000 to 75,000 KWH per month.

PARKER.

Municipal Electric Plant.

Equipment.	2 No. 165 Westinghouse Gas Producers. 1 Gas Engine, driving: 1 50 KVA 3-phase 60 Cycle 2400 Volt Generator. 2 Gas Engines, driving:
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	2 47.5 KVA 3-phase 60 Cycle 2400 Volt Generators.
Fuel	20 tons coal per month.
Peak	75 KW.
Output	10,000 to 12,000 KWH per month.
Operation	Meters newly installed. Record short. Average 2.5 coal per KWH. Power furnished Water Works.
Power Cost	About 5c per KWH at Switchboard.

PIERRE.

Municipal Electric Plant.

Equipment	2 Water Tube Boilers. 2 Uniflow Engines, direct connected to: 2 315 KVA 3-phase 60 Cycle 2300 Volt Generators.
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Note.—New plant not operating at time of visit.

Indian School.

Equipment	4 80 HP Return Tubular Boilers. 1 Simple Non-condensing Corliss Engine, belted to: 1 187.5 KVA 3-phase 60 Cycle 2300 Volt Generator.
Fuel	7 tons of coal per day. Cost \$7.50 per ton in bins.
Peak	170 KW in winter.

REDFIELD.

Municipal Electric Plant.

Equipment	2 200 HP Casey Hedges Water Tube Boilers. Steam Pressure 160 lbs. 1 Foster Superheater. Temperature 400° to 450°. 1 Westinghouse Steam Turbine, driving: 1 250 KVA 2-phase 60 Cycle 2300 Volt Generator. 1 Westinghouse Steam Turbine, driving: 1 125 KVA 2-phase 60 Cycle 2300 Volt Generator.
Fuel	3000 tons per year. Two-thirds Lignite, one-third Youghiogheny. Cost \$7.70 per ton delivered.
Operation	No meters or records. Heat 40,000 sq. ft. of radiation. In 1917 had 225 customers. 175 were metered. Now have 600 customers all metered.
Load	Average Daily Load, 21 hours at 75 KW and 3 hours at 200 KW.
Power Cost	Estimate 6c per KWH at Switchboard.

Co-operative Milling Company.

Equipment	2 80 HP Return Tubular Boilers. Steam Pressure 110 lbs. 1 85 HP Buckeye Piston Valve Engine.
Fuel	Illinois Egg Coal. Cost \$6.95 per ton.
Operation	Run 11 Hours per day. Capacity 300 bbls. per day.

Power from the Missouri River in South Dakota.

SIOUX FALLS.

Northern States Power Company.

Equipment	2 Boilers with Chain Grates.	
	1 Boiler with Roney Stokers.	
	3 Allis Chalmer Vertical Hydraulic Turbines 850 HP 60 ft. Head 300 RPM.	
	1 Steam Turbine, driving:	
	1 2800 KW 3-phase 60 Cycle 2300 Volt Generator.	
	1 Steam Turbine	
	1 Boiler	
	1 3000 KW Generator	} Installed in 1919.
Fuel	Coal cost \$6.18 in bins, 10,000 tons used in year ending April, 1919.	
Peak	Dec. 1918, 2800 KW; July 1919, 2180 KW.	
Operation	Have used as high as 5 lbs. coal per KWH.	

Municipal Water and Electric Plant.

	2 200 HP and 1 300 HP Water Tube Boilers.
	1 Snow Tandem Compound Non-condensing Pumping Engine. Capacity three million gallons per day.
	1 Holly Triple Expansion Vertical Condensing Pumping Engine. Capacity three million gallons per day.
Equipment	1 520 HP Diesel Engine, connected to: 1 450 KW Generator.
	2 Diesel Engines, connected to:
	2 135 KVA Generators and two three million gallon Triplex Pumps on same shaft.
Fuel	Fuel Oil 7c per gallon.
Operation	Pump against 165 ft. Head. Seventy-five Million Gallons in June 1919.
Output	1918 Total 432,240 KWH. Cost 1.53c per KWH. June 1919 22,901 KWH. Cost 1.74c per KWH.

Morrell Packing Company.

Equipment	4 308 HP Water Tube Boilers.
Fuel	73,000 Tons Coal used in 1918.
Operation	About 1000 HP of steam used daily, mostly for cooking.

Wilson Packing Company.

Equipment	2 50 HP Return Tubular Boilers.
	1 60 HP Return Tubular Boiler.
	1 85 HP Simple Non-condensing Corliss Engine.
	1 40 Ton Ice Machine.
Fuel	84 Tons Coal per 7-day week.

TYNDALL.

Municipal Electric Plant.

Equipment	2 100 HP Gas Producers. 1 65 HP Munzel Gas Engine, connected to: 1 45 KVA 3-phase 60 Cycle 2300 Volt Generator. 1 85 HP Munzel Gas Engine, connected to: 1 55 KVA 3-phase 60 Cycle 2300 Volt Generator.
Fuel	17 to 20 tons Coal per month.
Peak	100 KVA.
Output	April, May and June 1919, total 35,960 KWH.

VERMILLION.

Municipal Electric Plant.

Equipment	2 66"x16' Return Tubular Boiler. Steam Pressure 100 lbs. 1 12"x30" Non-condensing Corliss Engine. 1 12"x36" Non-condensing Corliss Engine.
Peak	Winter 125 KW. Summer 75 KW.
Operation	No data.

WATERTOWN.

Union Light and Power Company.

Manager absent and no data obtainable.

WOONSOCKET DISTRICT (Including six towns.)

Schuler Light and Power Company.

Equipment	1 175 HP Return Tubular Boiler. 1 Simple Non-condensing Murray Corliss Engine, belted to: 1 100 KVA 3-phase 60 Cycle 2300 Volt Generator. 1 Simple Non-condensing Murray Corliss Engine, belted to: 1 50 KVA 3-phase 60 Cycle 2300 Volt Generator.
Fuel	April used 120 tons Illinois Coal. Cost \$7.90 per ton in bin.
Peak	250 KW in winter; 150 KW in summer.
Output	For April 1919, 12,668 KWH used.
Operation	3 Shifts of one man each.
Power Price	Retail cooking rate 6c per KWH and 9c per KWH in adjoining towns. Motor rate 6c to 10c per KWH. Lighting rate 12c to 15c per KWH.
Town served	Artesian, Alpena, Lane, Forestburg, Cuthbert and Woonsocket; Also Cross Roads and Ruskin Park in summer.

WEBSTER.

Municipal Water and Electric Plant.

Equipment	2 150 HP Return Tubular Boilers Steam Pressure 110 lbs. 1 Simple Corliss Engine, belted to:
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Power from the Missouri River in South Dakota.

	2 25 KW Direct Current 125 Volt Dynamos.
	1 Simple Corliss Engine, belted to:
	2 75 KW Direct Current 125 Volt Dynamos.
	2 Single Cylinder Double Acting Deep Well Pumps. Driven by 10 and 15 HP Motors.
	1 20 HP Motor, driving:
	1 Triplex Pump.
Fuel	Youghiogheny coal. Cost \$8 per ton.
Output	For 11 weeks, total 58,200 KWH.
Operation	3 Men and 1 Superintendent. Use 8 lbs. coal per KWH.
Service	Six Grain Elevators and One Grist Mill in Town.

Webster Mills.

Equipment	2 Boilers 93 HP each. Steam Pressure 125 lbs. 1 12"x36" Simple Non-condensing Corliss Engine.
Fuel	Have used Pocohontas, Roundup, Elkhorn Screenings and Illinois Coal.
Peak	In winter 110 to 125 HP.
Operation	Tests with Various Kinds of Coal show 2½ to 3¾ lbs. Coal per Indicated HP. Daily Run 11 Hours. Bank Fires 13 Hours. Capacity 150-175 bbls. per day.

Note.—Boiler lasts about 8 years on account of chemicals contained in water.

YANKTON.

Union Light and Power Company.

Equipment	3 100 HP Return Tubular Boilers. 1 200 HP Simple Non-condensing Corliss Engine, driving: 1 150 KW 3-phase, 60 Cycle 2300 Volt Generator. 1 250 HP Simple Non-condensing Corliss Engine, driving: 1 200 KW 3-phase 60 Cycle 2300 Volt Generator. 1 75 HP Ball Engine, directed connected to: 1 75 KW 3-phase 60 Cycle 2300 Volt Generator.
Fuel	Iowa coal. Cost \$4.26 per ton in bin.
Operation	1260 KWH from 9679 lbs. Coal, or 7.7 lbs. per KWH. 3 Firemen and 2 Engine Men. 24 Hours Service. Furnish current to Water Works.

APPENDIX II.

PHYSICAL CONDITIONS AND FIELD INVESTIGATIONS.

GEOLOGICAL HISTORY OF THE MISSOURI RIVER IN SOUTH DAKOTA.

The original Missouri River is believed to have flowed eastward from the Rocky Mountains to the present James River valley and to have occupied that valley to the southern boundaries of the State. During the glacial invasion the courses of the various rivers of the State were almost wholly changed and their valleys rearranged. The old valleys of denudation developed by the eroding agencies of the ancient rivers and the accompanying atmospheric agencies were wholly or partially filled and their drainage areas largely rearranged. The flow of the ancient Missouri River toward the east was blocked by the ice sheet, its valley was filled with drift, and the waters were forced into its present channel which was essentially defined by the western limits of the glaciers of the last glacial epoch along the margin of which the modern valley extends from the great southerly bend in North Dakota to the point where it regains its ancient valley near the southern boundary of South Dakota. The river now occupies valleys or parts of valleys formerly occupied by other streams which had eroded channels to a much greater depth than that now occupied by the Missouri River. These ancient channels are now filled with sands, gravels and other deposits the upper portion of which have been and are now repeatedly modified and rearranged by the floods of the Missouri River.

DEPTHS TO THE ROCK BED.

Borings made prior to the construction of the Chicago, Milwaukee and St. Paul Railway bridge near Mobridge showed the rock surface of the old valley to be more than 120 feet below the present river bed, and indicate that the ancient main channel may have been still deeper and farther west than the west bank of the Missouri River at that point. In numerous places the borings made at various cross sections during our investigation (see Figures 14 to 19) show that the bedrock is at depths of more than 60 feet below the channel of the present stream, and that consequently any construction at such sites must be founded on sands and gravels at a considerable expense for foundation piling and sheeting to sustain the structures and cut off the underflow. On the other hand, the bed of the present stream at some points (see Figures 17 and 18) is entirely outside the limits of these preglacial valleys and passes perhaps through saddles in the ancient hills where the Pierre shale and the Niobrara limestone is fairly close to the surface and within reach of economic construction. Of the sites examined, this latter condition is particularly true at the Mo-

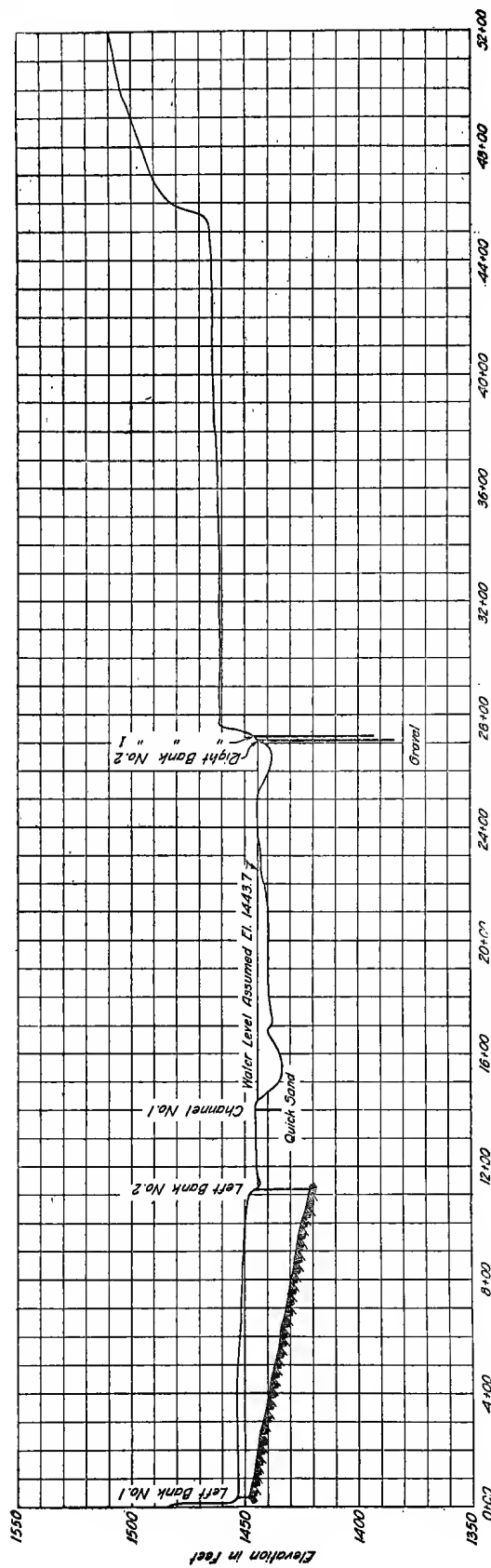


FIGURE 14. Cross Section and Borings at Medicine Butte Site.

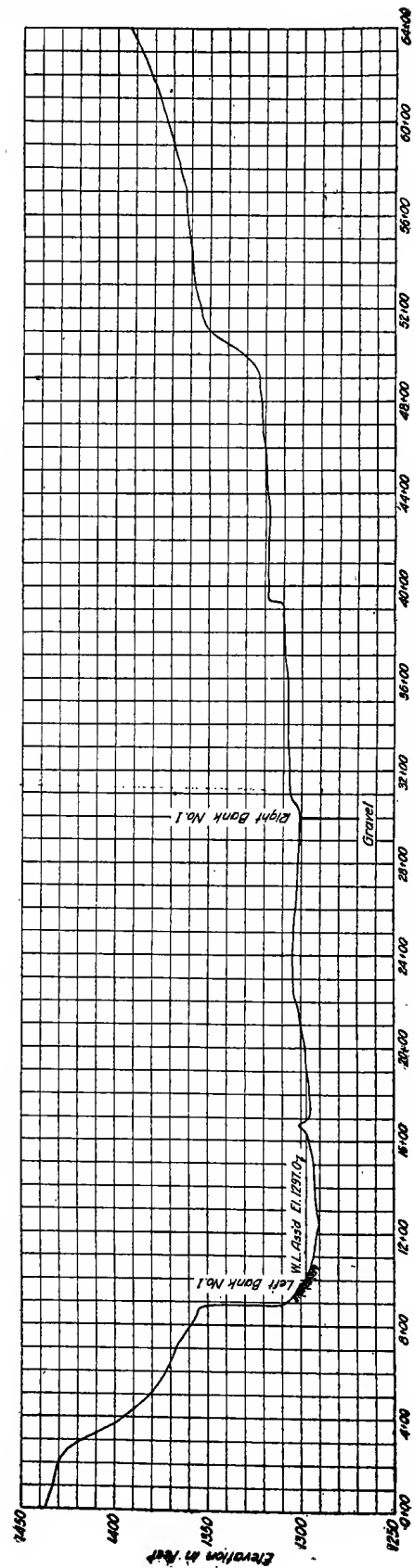


FIGURE 15. Cross Section and Borings at Little Bend Site.

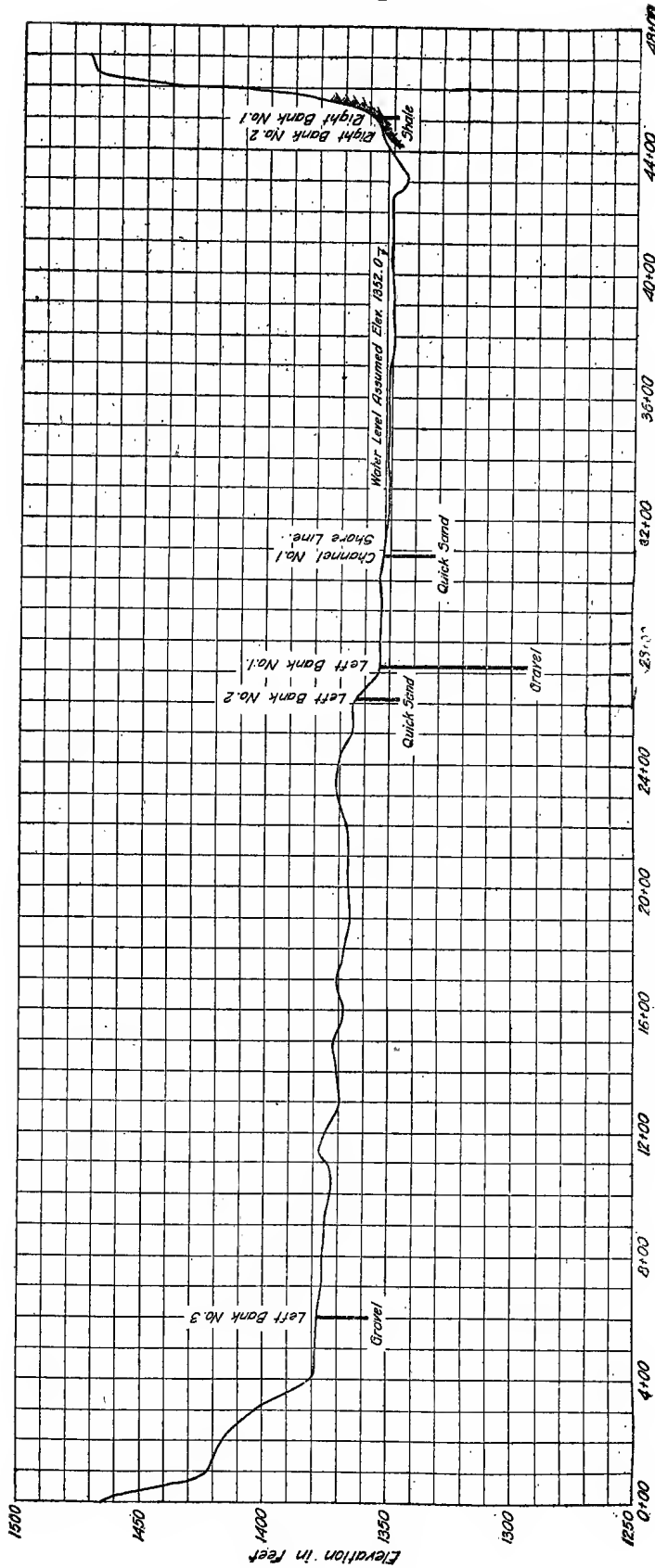


FIGURE 16. Cross Section and Borings at Reynold's Creek Site.

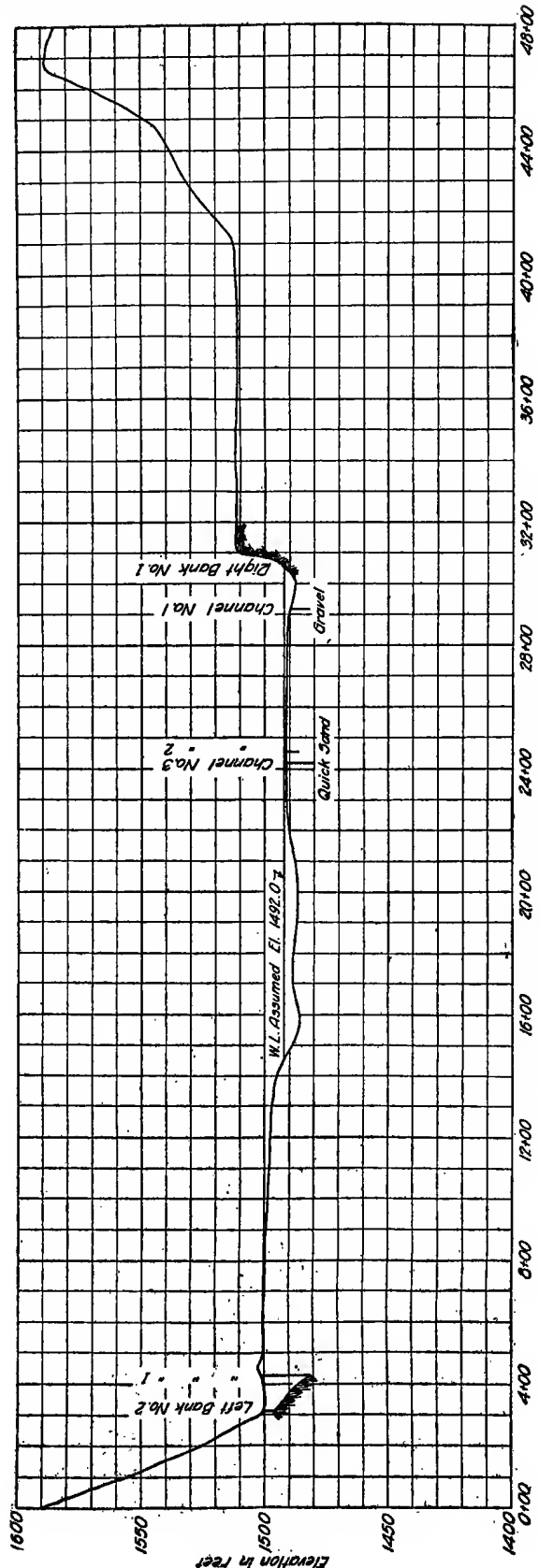


FIGURE 17. Cross Section and Borings at Bad Hair Site.

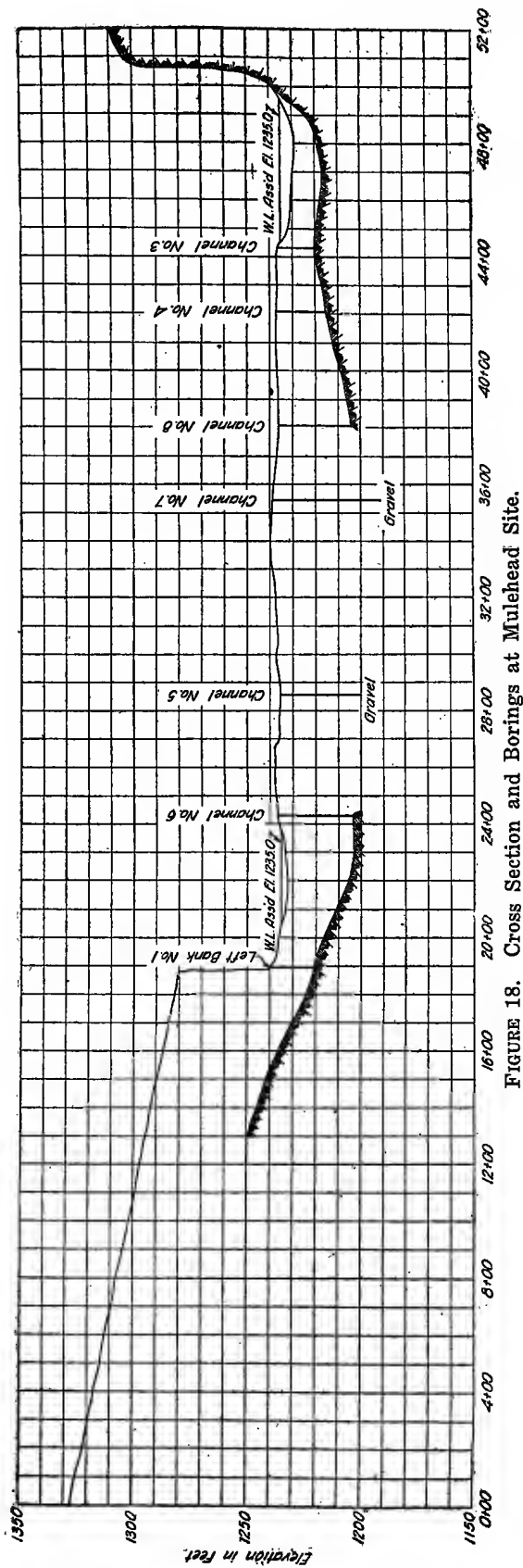


FIGURE 18. Cross Section and Borings at Mulehead Site.

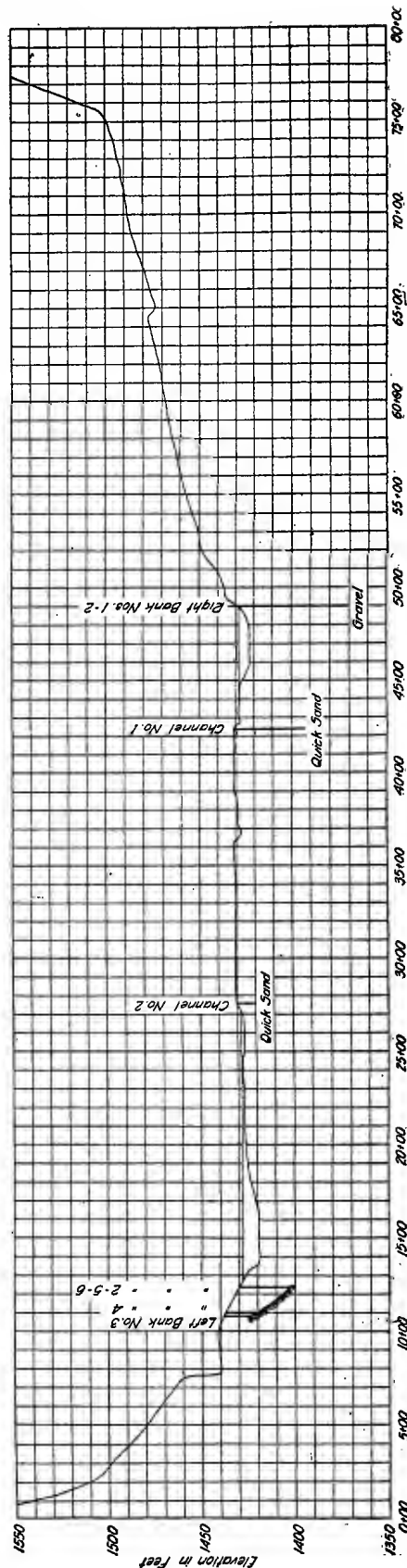


FIGURE 19. Cross Section and Borings at Chamberlain Site.

bridge (Figure 6) and Mulehead sites (Figure 18) which therefore render the foundation conditions at these points more favorable for safe and economical construction than any of the other river sites that we have examined.

THE RIVER VALLEY.

The Missouri River in South Dakota, confined as it is to the narrow valleys of preglacial streams, is in many places controlled in its meanderings by rock outcrops in the side of the valley which limits the possible extent of the flood plains and the lateral movement of the channel.

From the northern boundary of South Dakota the Missouri River waters are confined to a normal channel in the flood plains which varies generally from one-fourth of a mile to one mile in width and the flood plain is confined and limited by the hills and bluffs which outline the valleys of the ancient stream and now determine the general position and the direction of the present valley of the river. This flood plain has in general undoubtedly been worked over many times by the Missouri since it occupied its present valley, and in places the river has encroached upon and modified the original extent of the bluffs and hills of the ancient valley.

The valley of the Missouri south of the State of South Dakota is more ancient, and preglacial stream erosion has created a wider valley and a broader flood plain more nearly commensurate with the greater floods which there occur.

The rainfall normally increases from the Canadian boundary toward the south and gives rise usually to greatly increased floods relative to the drainage area of the tributary streams so that the lower river is subject to more numerous and relatively greater flood flows as described in detail in Appendix 3.

THE FLOOD CHANNEL.

The great flood of 1844, the highest known on the lower Missouri, filled the valley from bluff to bluff at Kansas City, Missouri, and was approximately two miles in width at that point. The great flood of 1881, the highest flood known at Pierre, occupied a channel only one mile in width. In each case the flood mentioned was relatively excessive, but at Kansas City the flood filled the valley between bluffs, while at Pierre the flood barely overflowed the banks of the channel. In the 28 years of recorded observation at Pierre, the banks of the river have not been overflowed, while at Kansas City extensive damage was experienced on the bottom lands during both 1897 and 1903.

The channel of the Missouri River undergoes continual changes in location, depth, and cross section. These changes are more rapid and more radical on the lower river but are slower and more limited in extent through most of South Dakota on account of the lower floods and the character of the materials that compose the banks. Such changes are however erratic and dependent on varying accidental causes, the channel filling when obstruction to flow decreases the velocities and the carrying capacities of the waters, causing deposition of the sand and silts which are carried; and eroding the channel and banks when the higher velocities of flood waters demand

a greater section for their accommodation. The processes of cutting and filling proceed with varying degrees of rapidity throughout the year, the low flows favoring deposition and filling, and the flood flows and flows below the ice sheet causing erosion.

GEOLOGICAL FORMATION OF THE MISSOURI VALLEY IN SOUTH DAKOTA.

The lowest geological formation exposed in the Missouri Valley above Yankton is the Niobrara, which underlies the Pierre shale. The Niobrara is cut through by the Missouri River, below the mouth of the James River and passes beneath the shale at water level just below the great bend of the Brule River Reservation. The purer Niobrara is described by Darton as "white or gray when dry, although often dull drab when freshly excavated. It weathers to a bright straw or bright buff color, which is a conspicuous feature in its exposures. It is in greater part massively bedded and is very fine grained and uniform in texture." The Niobrara consists mainly of chalk, which is its principal distinguishing characteristic in regions to the South. The formation grades into the shale above Chamberlain and its similarity to the latter confuses the two in the regions to the north.

The Pierre shale is the most extensive surface rock in the State and is the lowest formation exposed in the channel of the Missouri north of the great bend. Its maximum thickness is found above the mouth of the Cheyenne River where the overlying Foxhill Sandstone has protected the exposed surface from erosion, and it is estimated at approximately 1,000 feet in thickness. "The formation consists almost entirely of dark-gray clay, hardly sufficiently compact to be termed shale and presenting but little variation in its character from top to bottom."

The characteristic of both the Niobrara and Pierre formations, which effects their value as a foundation for hydraulic construction is the relative impermeability. The plastic consistency of the shale under water insures its freedom from fissures and gives homogeneity of structure that is well adapted to prevent underflow, and the Niobrara formation, under water, exhibits similar characteristics. Either is satisfactory as a foundation for construction. Bridge piers have been successfully founded on each formation and represent as great a concentration of loading as the proposed hydro-electric construction will involve.

PREVIOUS INVESTIGATION.

Honorable Doane Robinson, Secretary of the Hydro-Electric Commission had made some investigation of the more favorable power sites on the river prior to the undertaking of the work by this organization. Locations on the river that were apparently favorable to the topographical requirements of such projects were suggested. These sites were the first to be considered in our preliminary survey of the physical possibilities of power developments.

SCOPE OF INVESTIGATIONS.

Particular sites were first selected from apparently advantageous topographic conditions as determined from the maps of the Missouri River Commission and the

field party began more detailed investigation in the middle of June, 1919. Investigations were made at each of the following sites, in the order named.

1. Medicine Butte site, about ten miles north of Pierre.
2. Little Bend site, Cheyenne River Indian Reservation.
3. Reynold's Creek site, about forty miles south of Pierre.
4. Bad Hair site, eighteen miles south of Mobridge.
5. Mulehead site, twelve miles southwest of Platte.
6. Chamberlain site, Chamberlain.
7. Mobridge site, four miles north of Mobridge.
8. Big Bend, Brule River Indian Reservation. (Survey only.)

The extent of the investigations that were made at each site were limited to the borings, profile of the site, soundings of the river on the line of the profile, topographical surveys of the immediate dam site, and the location of any natural resources that could be used in construction.

THE MEDICINE BUTTE SITE.

Of the eight tentative dam sites considered, three were located within fifty miles of Pierre. Due to this fact and other considerations, headquarters were established at Pierre and work was first started at the Medicine Butte site which is about eight miles above that city. On the east side of the river, the Pierre shale was found at depths varying from five feet to twenty-seven feet and the material passed through to that depth was sand and gravel. A boring was taken on the west side of the sand bar where a depth of thirty-eight feet was reached through sand and gravel but at this depth, the tools were broken and a greater depth could not be reached with the apparatus available. An unsuccessful attempt was made to reach a greater depth on the east side of the sand bar. The difficulty in making these borings on the sand bar was caused by fine saturated sand that packed around the tools so tightly that it became impossible to move them at considerable depths. The length of cross-section at this site is about 4800 feet for a 30 foot dam. The attempts to find bed rock at this site were not satisfactory but the depths reached, showed that a dam built at this point would be relatively expensive on account of the nature of the foundation.

THE LITTLE BEND SITE.

The Little Bend site is located about forty miles above Pierre at a point where the Missouri River makes a bow of about twenty miles. The plan of development contemplated at this site was to build a canal across the neck of the bend with a dam at the upper end and the power house at the lower end of the canal so that the fall around the bend could be utilized in addition to head from the dam. The canal would be about two miles long at the narrowest place and a fall of about seventeen feet would be developed in addition to the head from the dam. Borings were started on the south side of the river at the proposed dam site, and Pierre shale was found at depths varying from five to twenty-six feet below the water surface. On the north

side of the river borings were made to a depth of sixty feet but did not reach bed rock. The material encountered was sand and gravel. Surveys were made of two possible canal routes each of which was about two miles in length, and the highest point of each above the upstream water surface was two hundred and fifty and two hundred and seventy feet respectively (See Figure 20). The length of the cross-section of the river at the dam site for a dam of 40 feet in height was about 4,500 feet (See Figure 15). Due to this great width of cross-section and the excessive depth of bed rock, the expense of building a dam at this point would be very great and the expense of digging a canal would be so great that construction of a power plant on the plans contemplated at this point would be impracticable.

THE REYNOLD'S CREEK SITE.

The Reynold's Creek site is located about forty miles below Pierre on the Crow Indian Reservation and about one mile above Joe's Creek, which is shown as Reynold's Creek on the government maps. On the west side of the river, Pierre shale was found one foot from the surface but borings of sixty feet on the east side failed to reach bed rock and encountered only sand and gravel. (See Figure 16). The distance between the banks is great on account of the wide flood plains on the east side of the river. The excessive depth to bed rock, indicated by the borings on the east bank, and the width of cross-section make the construction of a dam at this point relatively expensive.

THE BAD HAIR SITE.

The Bad Hair site is located about sixteen miles below Mobridge. On the east side of the river, Pierre shale was found at depths varying from five feet to twenty feet below the surface while on the west bank shale was found at the water surface and extended up into the bank (Figure 17). With this indication of shale on both sides of the river, an attempt was made to find the depth of the shale below the water surface in the channel of the stream. No satisfactory results could be obtained with the equipment available. The length of cross-section for a 30 foot dam at this site was 4,000 feet. From these results, no definite information can be given as to the depth of bed rock in the channel and further borings with more effective tools would be desirable if this site is to be further considered.

THE MULEHEAD SITE.

The Mulehead site is the most southern site that was investigated and is located about six miles above Wheeler. On the west side of the river there is an outcrop of very hard shale which extends for some distance both up and down the river. In boring on the east side of the river, a heavy red clay was encountered at the water level and extended down to shale which was found at fifteen feet below the water level. (Figure 18). At this site a large sandbar divides the river at low water into two channels. Borings were made on this bar at intervals and shale was found at varying depths as is shown on the profile. (Figure 18). The cross-section at this

site is narrow with a length of 3,100 feet for a 30-foot dam. A good gravel pit was located about one and one-half miles from the site. The physical features at this site favor economic construction, but the distance that a railroad must be built to reach the site would add considerable expense above the cost of construction at Mobridge.

THE CHAMBERLAIN SITE.

The Chamberlain site is located about one-half mile above the City of Chamberlain. On the east side of the river there is an outcrop of hard shale at the water level but on the west side of the river the borings showed that bedrock was a considerable distance below the surface. (Figure 19). The cross section is wide at this point and with bedrock so far below the surface on the west side of the river, the cost of construction would be relatively great.

THE MOBRIDGE SITE.

The Mobridge site is located about four miles above Mobridge. Pierre shale outcrops on the east bank of the river and was found 12 feet below the water surface on the west bank. Borings were then made on the island which here divides the river into two channels, and shale was found at all points where borings were made. (Figure 6). The physical conditions at this site, so far as foundations are concerned, were the best found in our investigation, and the cross section for a 30-foot dam is 3,100 feet in length. The Chicago, Milwaukee and St. Paul Railway is within a mile of the site so that the cost of constructing a side track to the site would not be great. (Figure 6). Gravel and boulders are also found within a reasonable distance of the site. Altogether the advantages of this site over the others investigated are considerable, and taking into consideration the limited power market and the lower flood flows of the river at this site, it seems to afford the best location for the first development of power on the Missouri River in South Dakota.

BIG BEND SITE.

This site is located on the Brule River Indian Reservation, about 45 miles below Pierre. A survey was made at this site but the great width of the low land on the north side of the river at the upper end of the bend would in itself render a development at this point impracticable at the present time. The height of the land at the neck would render a canal too expensive to consider, and the construction of a tunnel, besides being expensive, would entail the entire diversion of the low water flow through the tunnel and render low water navigation impossible. Owing to the above conditions, a full investigation at this site seemed unwarranted.

GENERAL RESULTS OF BORINGS.

While the borings with the light apparatus necessary for field investigation failed to determine the depth to bedrock at many of the sites, it was considered that such determinations were not essential, for such great depths could not be reached by economical construction methods. Considering the desirable lengths of steel sheeting

and the economy of driving, it was decided that about 50 feet was the economical limit to which complete cutoff into the shale or lines of sheeting to prevent underflow would be necessary, and that the rig used was sufficiently well adapted to the work to give comparative and satisfactory information in a preliminary way regarding the foundation possibilities.

The sections show the results of the investigations at the various sites. In general, our conclusion in regard to the possibilities of construction are that a safe development can be made at any of the sites; that at Mobridge and Mulehead are found the best physical conditions from the standpoint of first cost; that Mobridge, Mulehead, and Medicine Butte, in that order represent the best sites from the standpoint of economy of development.

BORING EQUIPMENT AND METHODS.

No definite information was available as to methods of securing satisfactory information from hand borings on a scale as extensive as were required in this work. A number of methods were tried out during the progress of the work, and included the use of various sizes of pipe, different types of boring tools and several arrangements for pulling the tools.

The boring tools were made of different types of augers and points welded to three-quarter inch pipe which were coupled to other sections of pipe to form a stem which could be lengthened as the boring progressed. These were forced into the ground by weights, driving with a maul and turning with wrenches, and were used with or without a casing pipe as the soil conditions required. Samples of the material were brought to the surface from the various depths by these boring tools which were pulled by lever, or by a differential chain block hoist supported by a tripod made of iron pipe.

STREAM GAGING.

The flow of the river was observed at two points, Pierre, where the longest record of gage heights has been kept, and Mobridge, where it was found desirable to observe the low water discharge. The gaging at Pierre was made from the Chicago and Northwestern Railway Bridge and referred to the gage on the protection pier 200 feet upstream from the draw bridge, and at Mobridge the gaging was made from the Chicago, Milwaukee, and St. Paul Railway Bridge and referred to the gage on the center pier of the bridge.

At each location the equipment used consisted of a Price electric current meter suspended from the bridge by a heavy brewery cord, through which the revolutions of the meter wheel were transmitted to the telephone head-set worn by the observer. An eighteen pound weight was used to maintain the position of the suspended meter against the flow of water, directly beneath the point of suspension. The equipment as it was used in the field was rated at Madison, Wisconsin, both preceding and following its use on the Missouri River, to determine the coefficient by which the revolutions per second of the wheel are multiplied to give the velocity of the water.

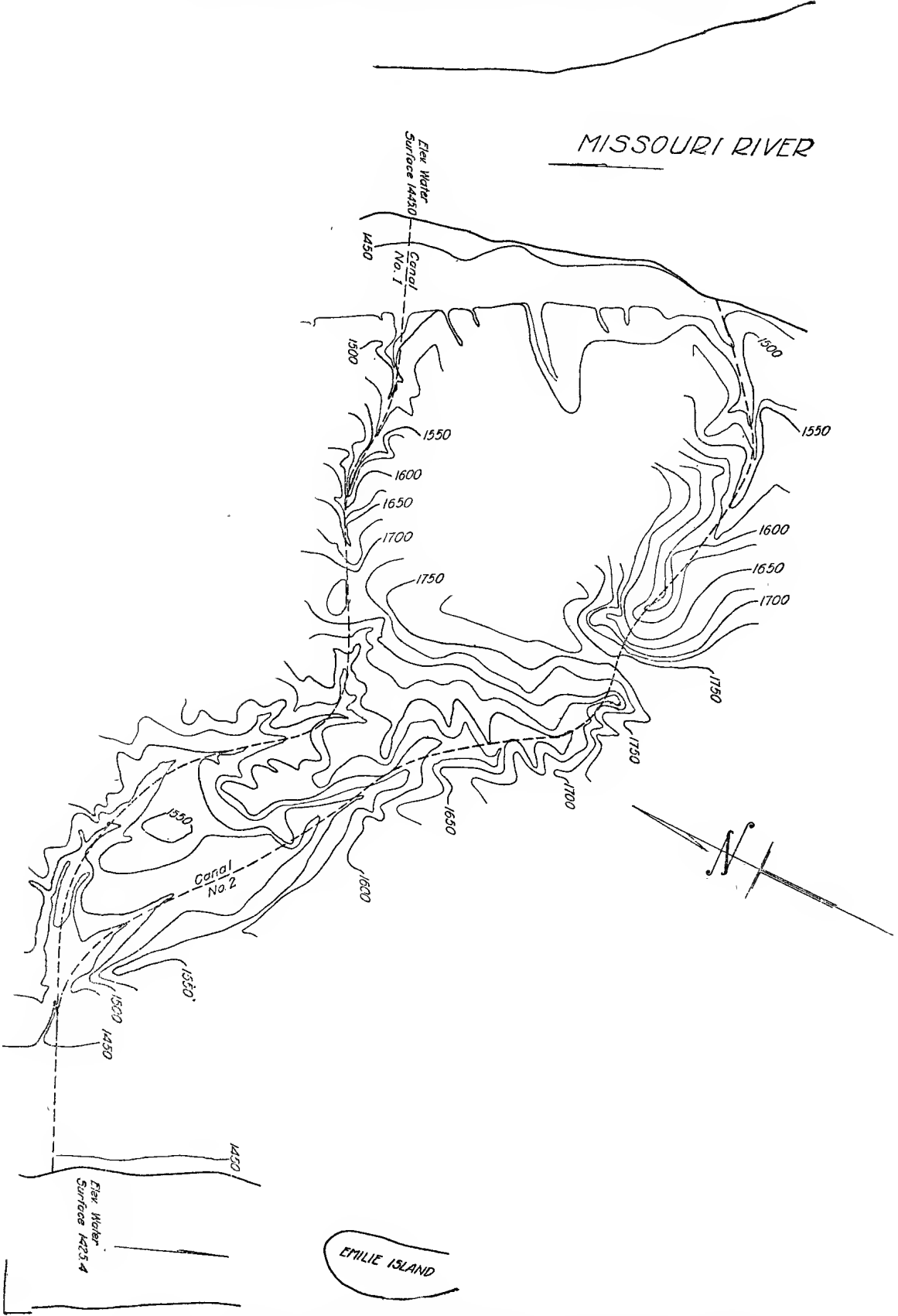


FIGURE 20. Topographic Map of Possible Canal Locations at Little Bend Site.

Nine gagings were made at Pierre at gage heights varying from +5.0 feet to the zero of the gage and one gaging was also made under ice conditions. At each gaging, observation was made at 50-foot intervals across the 1800' channel, and at 3' and 10' distances from each pier in addition. Where the depth of channel permitted, the velocities at .2 and .8 depths were measured and in other cases the value at .6 depth was taken as the average at that point.

Three gagings were made of the low water at Mobridge with method similar to that used at Pierre. The width of the channel at Mobridge is about 800 feet.

APPENDIX III.

THE FLOW OF THE MISSOURI RIVER.

STREAM FLOW RECORDS.

Records of the stages of water in the Missouri River begin at Fort Leavenworth, Kansas, January 1, 1872. During 1872 and the year following, records were also begun at St. Joseph, Kansas City, Hermann, Boonville and Lexington in Missouri, and at Omaha and Plattsmouth in Nebraska. The gages were established by the U. S. Signal Service, with the exception of the gages at St. Joseph and Omaha, which were placed and read in connection with bridges constructed across the river at those points.

In 1878 the U. S. Army Engineers equipped observation stations along the Missouri River, taking over or re-establishing stations at most of the points listed above with additional stations at Atchison, Kansas, Glasgow, Waverly, Jefferson City, St. Charles, Missouri, Nebraska City, Nebraska, and Sioux City, Iowa, thus increasing the number of government stations to fifteen and embracing an extent of river under observation from its mouth to the southern boundary of the state of South Dakota. Readings at these stations are essentially continuous from 1878 to 1886 and furnish the only early data of the flow of the river.

The first records of gage heights on the river within the State of South Dakota were made at Vermillion from May 19, 1879 to October 14, 1882, at which latter date observations were discontinued. The longest record of gage heights on the river within the state were taken at Pierre from 1892 to date. Though there are interruptions to the continuity of the record and complications in the application of the published gage heights to our observations of the stream flow in 1919, these records are the most serviceable of those available, principally because of the central location of Pierre with respect to that portion of the Missouri River with which this report is concerned. At points on the river near the boundaries of the State, records are available from the government stations at Bismarck, North Dakota from 1891, and at Sioux City, Iowa, from 1878 to date. Thus the data on river stages for the 28 years of observation at Pierre are fairly comprehensive for the purposes of this investigation and are supplemented by the other observations mentioned from which the Pierre data may be modified for other locations on the river within the state.

Other government gages were subsequently established in South Dakota at Running Water and at Chamberlain in 1908. North of Pierre a gage was established and maintained at Mobridge by the Chicago, Milwaukee and St. Paul Railway and affords a record of gage heights from 1911 to date.

THE PIERRE GAGE RECORDS.

The record of gage heights at Pierre is short in comparison with similar record on the Missouri at points further downstream and are further complicated by the fact that three different gages, located at different sites and not fairly comparative, were used during this period. The field work of the past year included the determination of the relations of gage heights on the present gage to quantities of discharge. The use of the rating curve of 1919 is limited to the flood flows of the river in 1918 and 1919, for prior to 1918 the records were taken from other gages located at other points where different channel conditions give rise to readings which cannot be accurately correlated. The derivation of safe conclusions from these gage heights in regard to the extreme conditions of flow entails comparative study of other factors of stream flow.

THE PIERRE GAGES.

The first gage at Pierre was read from March 1892 to July 6, 1896, when this gage was abandoned. From March 27 to July 6, 1896, gage readings were taken on both Gage 1 and Gage 2 which were located on opposite sides of the river. The difference in the readings on these Gages was recorded daily for this period giving 102 observations in direct comparison, by means of which we have attempted to establish a relation that will hold for the extreme flood and minimum records.

The second gage was read until March 4, 1916, when it was destroyed by a flood. No readings from that time are on record until 1918 when the Chicago and Northwestern Railway commenced the readings on Gage 3, located on the protection pier above the draw pier of their bridge across the river, and over a mile above Gages 1 and 2. No simultaneous readings are available for comparison between Gages 2 and 3, since the former gage had been destroyed before the latter was established and the method employed in the establishment of the present gage gives the only clue to the relations between the two.

The observer at the local office of the Weather Bureau at Pierre advises us that Gage 3 was so placed as to read five feet when levels from the bench mark at the Stock Growers Bank in Fort Pierre to the water surface at the location of Gage 2 indicated a corresponding gage height at that point, with a difference in level of water surface at the two gages of 2.2 feet. Our own determination of the difference between water surfaces was made at a height of 2.5 feet on Gage 3. A difference of one foot was found at that stage. It is apparent from these results that the actual relation between the stages at the bridge and those downstream will not admit of ready comparison and that the observations are too limited in number and too indefinite in character to fix the relation that would exist under all conditions.

The government records of the gages and gage heights of the river at Pierre are contained in the annual reports of the Weather Bureau publication "Daily River Stages." From these reports the following description of Gages 1 and 2 have been taken.

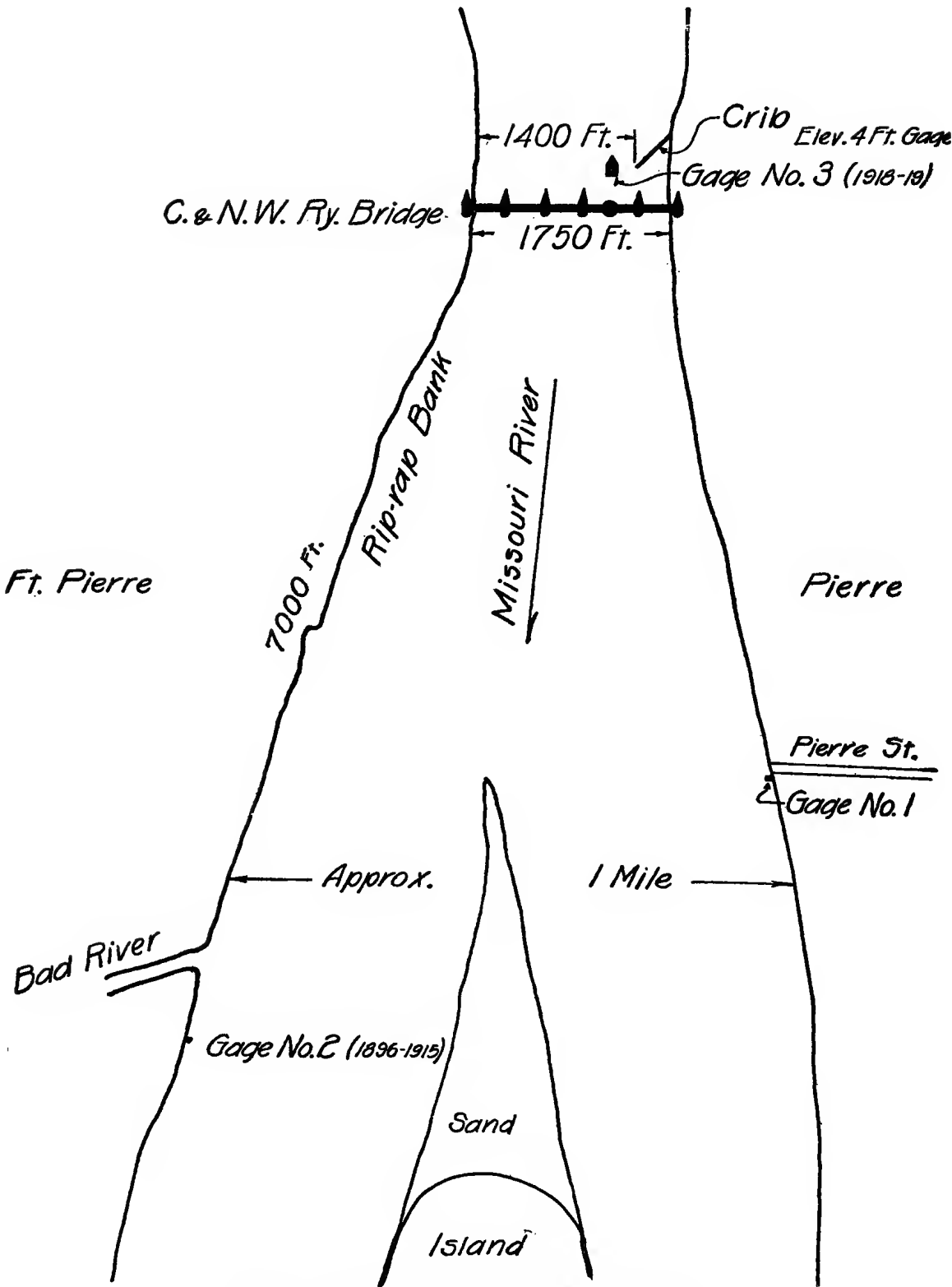


FIGURE 21. Locations of Gages 1, 2 and 3 at Pierre.

Description of Gage 1 from Daily River Stages, 1896.

“Pierre, S. Dak., is on the Missouri River, 330 miles above Sioux City, Iowa. The width of the river at low water is 2625 feet and at high water, 5280 feet. The drainage area above the station is 243,600 square miles.

“The river gage is of wood, painted white, and graduated by copper tacks. Readings after Dec. 31, 1895, will be taken from the United States Engineers’ gage at Fort Pierre, on opposite side of river. Weather Bureau bench mark, on the first stone step at entrance to the National Bank of Commerce Building, is 32.8 feet above zero of gage.

“Graduation is from 2 feet below to 20 feet above zero. Highest water was 21 feet in March 1881; lowest, —4.2 feet on November 18-19, 1893; danger line is at 13 feet.”

Description of Gage 2 from Daily River Stages, 1900.

Pierre, S. Dak., is on the Missouri River, 1,114 miles from its mouth, and 330 miles above Sioux City, Iowa. The width of the river at low water is 2625 feet, and at high water, one mile. The drainage area above the station is 243,600 square miles.

“The old river gage was of wood, painted white, and graduated in copper tacks. It was abandoned on July 6, 1896, and since that date readings have been obtained from the United States Engineers’ gage at Fort Pierre on the opposite side of the river. This gage is a horizontal pipe beam, with cable and weight, the markings being cut on an oak plank. It is located 350 feet below the mouth of Bad River on a revetted bank.

“Bench mark, Upper Missouri River Commission, No. $\frac{248}{1}$ is 1451.6 feet above mean sea level, and 36 feet above zero of gage. It is a flat rock, 4 feet under ground, with an iron pipe extending from the top of the stone to the surface of the ground. It is 700 feet back from the river, the same distance above Bad River, and on Gumbo Hill, just back of houses on Deadwood St. Bench mark on southeast end of first step from sidewalk at entrance to Bank of Commerce, in the town of Pierre, is 25.8 feet above zero of gage, and 1441.1 feet above mean sea level.

“Graduation is from about 8 feet below to 15.3 feet above zero. Highest water was in March, 1881, 21 feet; lowest, —4.2 feet on November 18-19, 1893. Danger line is at 14 feet.”

Description of Gage 2 from Daily River Stages, 1916.

“In the Missouri River, 248 miles above Yankton, S. Dak., the gage is located on the right bank of the Missouri River, 280 feet below the mouth of Bad River, on a revetted bank. It consists of a 4 by 12 inch horizontal timber, supported on five piles driven solidly into the ground; along the upper side of the timber, eye-bolts are set in line, and through them is passed a gas pipe, 32 feet in length, and so placed that the end next the river can always be made perpendicular to the point where the water surface touches the bank. In the end of the pipe is fitted a plug

with a sharpened point, and this constitutes the datum point of the gage. In taking readings the datum point is adjusted so as to come directly over the edge of the water. The observer takes an engineer's leveling rod, which is provided with a bubble to insure perpendicularity, and measures the distance from the datum point to the water surface. The datum point is 1,430.5 feet above mean sea level or 14.5 feet above the zero of the old gage. The Weather Bureau continues to use the old zero

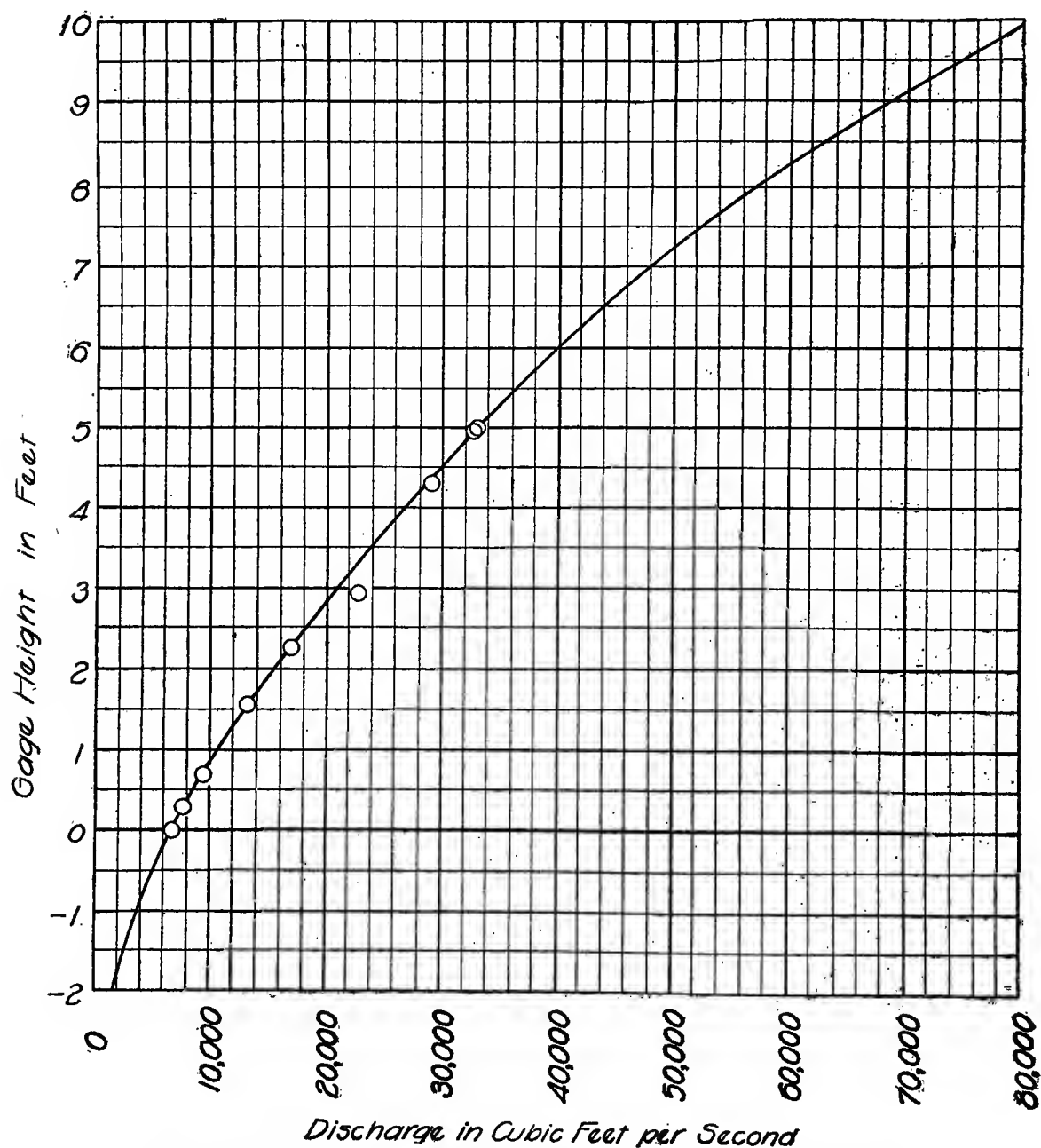


FIGURE 22. Rating Curve of Missouri River at Pierre for Summer of 1919.

elevation, and to all readings from the new gage a correction of +14.5 feet must be applied. Graduation extends from about 2 feet below to 15 feet above zero.

P. B. M., Upper Missouri River Commisison, corner of cement sidewalk, at corner of Stock Growers Bank, Fort Pierre, and marked by a stone with pipe and cap, stone being below frost line, is (top of cap) 20 feet above the zero of the gage and 1,436 feet above m. s. l. B. M., Upper Missouri River Commission, No. $\frac{248}{1}$, is a flat rock 4 feet under ground, with an iron pipe extending from the top of the stone to the surface of the ground. It is 700 feet back from the river, the same distance above Bad River, and on Gumbo Hill, just back of houses on Deadwood Street. Elevation above zero of the gage 36 feet; above m. s. l., 1,452 feet. B. M., on S. E. end of first stone step from sidewalk, at entrance to Bank of Commerce, in the town of Pierre, is 258 feet above zero of the gage and 1,441.8 feet above m. s. l. Zero of gage corresponds to low-water mark of 1889."

DISCREPANCIES IN ELEVATIONS OF THE GAGES.

Apparent discrepancies in elevations of the zeros of the gages as computed from the government records necessitated further examination of the probable relation between gages. Wherever possible actual measurements have been made, and the office of the Weather Bureau has been of material aid with a filed record of the gages and their successive replacement.

The elevation of the present gage is uniformly given as 1,417.1 feet above mean sea level and is referred to the old Bank of Commerce bench mark in Pierre. The elevation of that bench, to which the elevations of gages 1 and 2 also are referred, was corrected by a second survey in 1911, and for the purpose of comparison the latest elevation for this bench mark of 1,440.7 instead of 1,441.4 is used for all the gages. The records of elevations of the Pierre gages showing the discordance in gages 1 and 2 are as follows:

TABLE 13.
Records of Pierre Gage Elevations.

Source of Record.	ELEVATION OF DATUM.		
	Gage 1	Gage 2	Gage 3
1. D. R. S. 1896	1407.9	.....	.....
2. D. R. S. 1900			
Ft. Pierre B. M. ....	.....	1415.6	.....
Bk. of Comm. B. M. ....	.....	1414.6	.....
3. D. R. S. 1916			
Ft. Pierre B. M. ....	.....	1416.0	.....
Mo. R. Comm. B. M. ....	.....	1416.0	.....
Bk. of Comm. B. M. ....	.....	1414.9	.....
4. Field Work 1919 .....	.....	.....	1417.1
5. Statement by W. B. 1919	1418.5	1416.1	1417.1
6. Letter W. B. 12-3-19 .....	.....	1414.9	1417.1
7. Letter W. B. 12-8-19	1416.1	1414.9	1417.1

ESTABLISHMENT OF A RATING CURVE AT PIERRE.

In order that a relation might be established between stream flow and river heights as shown by Gage 3, a series of gagings were made during the summer and fall of 1919, of the Missouri River at the Chicago and Northwestern Railway Bridge at Pierre.

The manner of taking these gagings is described on page 75. In order to establish a relation between the river heights as shown by Gage 3 and the corresponding flow of the stream, the measurements made at each gaging were plotted in relation to the corresponding gage heights and a curve was drawn through them and extended to higher gage heights than those for which observations were made. This extension furnishes an approximate measure of the flood corresponding to such gage heights. The various measurements and the resulting rating curve are shown in Figure 22. From this curve the flow of the river from day to day corresponding to the daily gage height at Gage 3 can be determined with reasonable accuracy.

The section of the river channel at the gaging section is artificially modified by the bridge piers and appurtenances. Below a height of four feet on Gage 3 the low water channel is reduced in length by the bridge piers, riprap on the bank and a deflecting crib, to 1,340 feet.

It must also be noted that the soft bottom at this section is subject to scour which undoubtedly affects the relations of river heights to stream flow at low stages so that any rating curve will be reasonably accurate only for a limited time and will not closely show the relative flows of other years when a deeper or shallower channel will modify these relations.

It will readily be seen that this rating or discharge curve is applicable only to the station for which it is made, for the character of the river section varies greatly from place to place. This is especially true when comparing the section at the bridge with other sections of the river. At the bridge the clear waterway is only 1,340 feet, whereas at the locations of Gages 1 and 2 the available width at flood stage is approximately one mile. When the channel flows full, the effect of the four to one increase in width between the two points on the river is accompanied by a considerable reduction in depth of water in the channel. At the gaging station the increased depth of channel may appear as a deepening of the low water bed or as a higher gage reading since the obstruction causes the water to pile up under and above the bridge. The gage heights therefore do not afford a basis of comparison of the stream flow for other years with that for 1919. This is especially true of the low water stages, for the washing out or filling in of the channel, even at a single station, may result in a difference of a foot or more for the same flow in different years. Some comparison, however, has been made to estimate the minimum flow that has occurred and might again be expected, and a direct relation has arbitrarily been taken as the basis of gage reference in such study.

STREAM FLOW.

The period of 28 years for which there is record of river stages above Sioux City, Iowa, does not include the years of extreme flood but does include the years of probable minimum flow, and further indicates the annual and seasonal fluctuations of the river.

Practically without exception the high water flow of each year will occur in two periods; the first in March or April, and the second in June or July. The March or April rise accompanies or follows the breaking up of the ice in the river, and the rise in June or July follows the release of winter snow on the mountains at the headwaters of the river. Of the two peaks the first represents the larger volumes and the more extreme conditions which have to be met and the second, while of less volume, is of greater duration and its volume accumulates and falls off more gradually.

The minimum flow occurs after the recession of the June or July flood, usually in September, October or November, and a study of the minimum stages shows a tendency for that minimum to precede the freezing of the river. The published data do not carry the record into the months when the river is closed, but undoubtedly the minimum flow will occur under ice in the greater number of years.

A paper by James A. Seddon, Assistant U. S. Engineer, which was published in the House of Representatives Document No. 141 in 1898, in connection with Chittenden's report on "Reservoirs in Colorado and Wyoming," includes a study of the floods on the Missouri River from 1880 to 1885, both years inclusive. In regard to this period Mr. Seddon says:

"In point of time the six years from 1880 to 1885 have been selected for this study. It is a period fairly covered by the observed discharges and includes about the extreme and average combinations of which we have anything like definite records. It might have been extended, but to do so would be little more than needlessly to multiply data; and as it is, the period covers a group of extreme floods from the Missouri, Upper Mississippi, and Ohio Rivers, and includes those phenomenal high waters at Cairo in the years 1882, 3 and 4. * * *

"Following 1881, which is the only instance known where a head rise above Sioux City has reached anything like such volumes, 1883 shows the more general type of high floods in the Missouri."

THE MAXIMUM FLOOD.

In accord with Mr. Seddon's observations it is generally accepted that the flood of 1881 is the highest that has passed Pierre within the memory of the present generation. The stage of the flood is recorded as 21 feet, but the volume of flow can be only approximately estimated.

The government record states that the highest flood at Bismarck, North Dakota, occurred in 1887, with a stage at that station of 27.1 feet which we estimate to equal approximately 300,000 cubic feet per second. Apparently, therefore, the rise from the upper river in 1881, which produced the maximum rise at Pierre and an abnor-

mal volume of water at Sioux City, was furnished in unusual proportions by the streams tributary to the Missouri at points below Bismark. The data further indicate that the Canon Ball, Grand, Moreau, and Cheyenne Rivers contributed to the flow of the river in such volume as to increase the flood in 1887 to exceed 300,000 second feet at Pierre.

From Seddon's study it is noted that the same amount of flood water, namely 550,000 cubic feet per second, passed Sioux City, Kansas City, and St. Charles with an interval of three days between Sioux City and Kansas City. It is a matter of considerable uncertainty as to what proportion of the 550,000 second feet was carried by each of the tributaries above Sioux City, yet from the fact that undoubtedly the volume of the flood at Pierre was in excess of 300,000 second feet, it is reasonable to assume that the larger portion of the Sioux City flood had accumulated above Pierre and passed that station. The above conclusion is further confirmed from another consideration. A stage of 5 feet on the river at Pierre represents approximately 33,000 second feet of flow at an average velocity of 2.53 feet per second through a cross sectional area of 13,000 square feet. From measurements taken in the field the past year, the cross sectional area of the stream at 21 feet is over 86,000 square feet. No definite tendency of the average velocity to increase with the discharge and therefore with the area can be deduced directly from the small increases observed in the comparatively narrow range of data secured during the summer of 1919. The most conservative conclusions from such calculations as we are able to make, are that the velocity at a stage of 21 feet would be 5.2 feet per second with a consequent discharge of 450,000 cubic feet per second.

It is doubtful whether above the Grand River the peak of the 1881 flood at Mobridge attained a magnitude as great as 300,000 second feet, although in 1887 a flood of that amount undoubtedly passed that location.

The peak of the flood of 1881 was exceeded at Sioux City in 1892 but without a rise from the upper river as in 1881, for the stages recorded for both Bismark and Pierre for 1892 are normal. It may therefore be concluded that for the period of 40 years for which there are river data at Sioux City, the flood of 1881 was the maximum occurring on the Missouri at Pierre; the flood of 1887 was the maximum between Bismark and Mobridge; and the flood of 1892 was the maximum near the South Dakota-Iowa boundary.

The manner in which the floods of 1880 to 1885 accumulated over the drainage areas is shown graphically in Figure 23. The floods at Sioux City, Kansas City and St. Charles are plotted, and the extensions of curves through those points to intercept the drainage areas of Pierre and Mobridge show roughly that the origin of the peak of the floods was in the lower tributaries. It is noted that in 1881 and 1884 the quantity of water passing Sioux City, Kansas City and St. Charles is the same. It is also noted that the flood peak of those years occurred in the spring. In the other four years shown by the diagram, the flood peaks on the lower river occurred in June, and most of the volume at St. Charles originated from tributaries below Sioux City.

The Maximum Flood.

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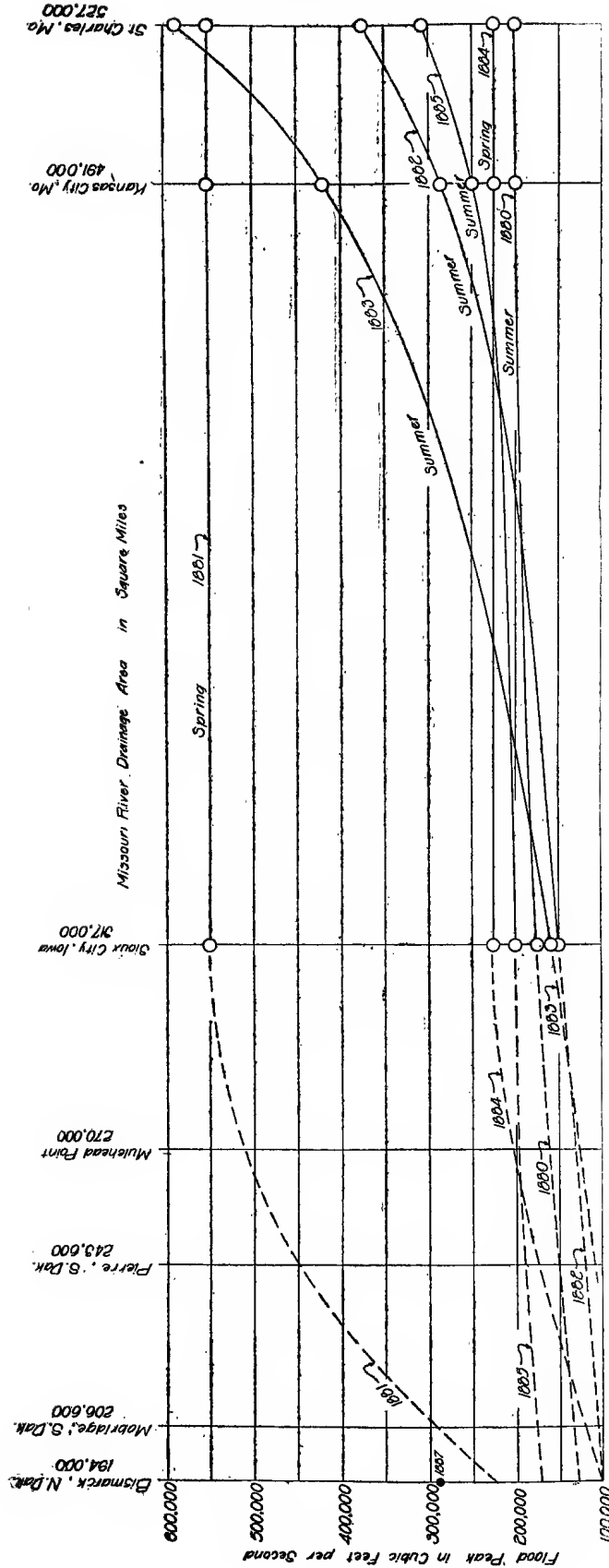


FIGURE 23. Diagram Showing amount of Maximum Flood Waters at Various Stations on the Missouri River, from 1880 to 1885.

In brief, during two years of the six shown on the diagram the maximum stage of the river resulted from rises in the upper river and the tendency of flood water to accumulate. In only one instance did it attain great volumes up stream, which would indicate the rare character of floods similar to the maximum flood of 1881.

It is readily conceivable that, although the particular floods of 1881, 1887 and 1892 discussed in the preceding pages so originated and were so discharged as to bring about the maximum flood conditions in 40 years at various points on the river in South Dakota, the natural factors which control the origin and distribution of Missouri floods might combine to cause a maximum flood of perhaps five hundred thousand second feet as far north as Mobridge, without materially increasing the discharge of the lower river above the flood peak of 1881, or to exceed the larger flood peak of 1892.

It is equally inconceivable that the drainage area above Mobridge would receive precipitation sufficient to produce a flow in excess of 500,000 second feet under any probable rainfall distribution. If the design at Mobridge provides for a maximum flow of 500,000 second feet it will accommodate extreme conditions sixty percent. in excess of any floods that have been experienced in forty years of observation.

A report to the Weather Bureau by Mr. P. Connor, Forecast Official at Kansas City, Missouri, in regard to the high water of the Mississippi and Lower Missouri in 1897, discusses the flood of 1844, which Mr. Connor states is the highest known on the Missouri River. This abnormal flood was occasioned by the combined effect of the breaking up of the ice on the river and continuous heavy rainfall.

How far upstream the effect of this unusual precipitation produced increase in flood conditions is largely conjecture. The rainfall on the area drained by the Upper Missouri is so uniformly low that a marked departure sufficient to cause a flow in excess of the maximum estimated is not likely.

LOW WATER FLOW.

The relations of gage height to flood discharges are more constant than for low water flows because modifications in the channel have less comparative effect on high than on low discharges. Modification of low water channel sections may greatly increase or decrease the low water discharge which will occur at a given gage height. High floods may clear out the low water channel and cause larger discharge for a given gage reading while low floods may congest the low water channel, and the corresponding flow for a given gage height may be abnormally small.

At the lower stages, therefore, gage heights alone are poor evidence of the actual amount of water flowing. The relative amounts of seasonal precipitation and the manner in which it appears as runoff throughout the year are the principal factors that modify the low water discharges. They may reasonably be considered better evidence than gage heights where no records are available as to the conditions of the channel.

Of the 28 years for which there are river data at Pierre, twenty years include

stages during the period of low water. In six years of the twenty the minimum stage of 1919 is higher and in fourteen, lower than the lowest recorded for those years, but study of both gage records and other pertinent data lead to a different conclusion as to the relative low water flow of 1919. These conclusions may be regarded as radical and the basis for this conclusion will be considered in detail.

The six years lower than 1919 are 1893, 1897, 1904, 1906, 1907, and 1908 according to the published gage heights with stages of —4.2 feet, —1.1 feet, —1.9 feet, —0.9 feet, and —0.5 feet respectively as compared with —0.4 feet in 1919 at Gage 3. The stage of 1893 was recorded on gage 1, the others, on gage 2, while the low water of 1919 was read on gage 3, which is now in use and to which the only available rating curve of the river at Pierre is referred. For the following reasons the published stages can not be taken as conclusive as to either the occurrence or volume of the low water flow, viz:

1. More than one elevation is ascribed to each of the gages formerly in use, and each is equally authentic and unreconcilable with the others.

2. Due to different locations and dissimilarity of conditions, there is a variable relation between gage heights which has not been accurately determined and which has been only partially and roughly considered in the past. This is sufficiently complicated to render inadvisable any investigation to the extent necessary to determine their reliability.

3. The stage of the river at low water is at best only a rough indication of the amount of water discharged.

The stages from 1892 to the date of establishment of the present gage are not directly comparable with the 1919 readings. Unfortunately the correction is not calculable, and a judgment, based upon all the facts discovered in the investigation must determine both the amount and character of the correction to be applied.

During the following months of the years indicated, the *minimum* gage height for the month is greater than the *maximum* for the corresponding month of 1919:

1893—None.

1897—May, June, July, August and September.

1904—May, June, July, August, September, October and November.

1906—June, July, August, September, and October.

1907—July, August, September, and October.

1908—July, August and September.

With the exception of the following, the monthly maximums of the years exceed those of 1919:

1893—October and November.

1907—April.

1908—March.

1897—October.

1904—None.

1906—April.

To compare average conditions, the following tabulation shows the algebraic difference between the average stage each month and the corresponding average in 1919:

Year	Mch.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.
1893 ...	....	0.91	—2.38	—0.16	3.17	0.18	—2.10	—3.65	—3.85
1897 ...	....	2.72	3.27	3.42	4.36	2.81	1.48	0.54	1.14
1904 ...	0.50	2.60	3.00	5.09	5.66	3.87	3.15	1.48	1.99
1906 ...	....	2.10	0.00	3.49	3.25	2.27	2.15	0.88	—0.01
1907 ...	1.30	0.10	0.60	3.39	6.75	4.47	2.45	1.18	0.69
1908 ...	—2.10	—2.80	—0.10	4.89	5.45	2.77	2.45	1.58	1.99

With the exception of the year 1893 the average quantity of water preceding the minimum water of the year in each of the six low years is nearly double that preceding the minimum of 1919. The effect of the larger discharges preceding the low water is to clear out the low water channel to greater depths and admit of a greater minimum discharge at low water gage heights in each of the five years (excepting 1893) than in 1919. The recorded stages of the years previously referred to would indicate minimum discharges less than the minimum of 1919. They are, however, modified by an indeterminable amount.

LOW WATER OF 1893.

The cumulative precipitation of the winter months determines largely the annual discharge of the headwaters of the Missouri. As is pointed out later, the precipitation during the other months of the year is taken up in various ways and only in cases of extremely abundant rainfall would that precipitation materially increase the run-off on the area considered.

The total precipitation during December, January, February and March preceding the low years is taken as the precipitation which sustains the flow of the river throughout the months of open flow. The total flow during values of the open season have been taken from the 1919 rating curve corresponding to the average monthly gage heights and are shown in Table 14.

TABLE 14.

RELATIONS OF OPEN SEASON DISCHARGE AND WINTER PRECIPITATION FOR
YEARS OF MINIMUM FLOW.

Year.	Total Dis- charge for Open Season in Billions of Cubic Feet.	Winter Pre- cipitation Inches.	Discharge per Inch of Win- ter Precipita- tion. Billions of Cubic Feet.
1893	323	3.53	91.6
1897	596	3.14	189.5
1904	743	3.48	213.5
1906	475	2.41	197.2
1907	681	3.68	185.0
1908	572	2.84	201.1
1919	388	2.16	179.5

If the published gage heights for Gage 1 are fairly comparative with those of Gage 3, the river discharge for 1893 shows a marked departure from the average rainfall-runoff relations. It is our opinion that the recorded stages indicate discharges too low rather than that the rainfall-runoff relations vary as widely as indicated in Table 14 for the year 1893. If the stages for 1893 be assumed to be uniformly four feet higher than recorded, the discharge becomes 521 billion cubic feet, and the discharge per inch of winter precipitation 145 billion cubic feet.

Finley, in his treatise on "Certain Climatic Features of the Two Dakotas," published in 1892, has made rather an exhaustive study of the great drought from 1887 to 1891. In that latter year he points out a decided lifting of the drought and a change in all climatic features. Both winter and summer precipitation were abundant, and the runoff in the streams correspondingly larger. Then in 1892, the year of high water at Sioux City, the discharge of the river was again large, with the result that the low water bed of 1893 was doubtless very materially scoured by practically three years of high water.

So far as the low water of 1893 is concerned, in view of the uncertainties involved in the government data and the conclusions that may be drawn from the data just discussed, there is an appreciable correction to be applied to the gage heights which raises the minimum well above the minimum of 1919. A letter from the local observer of the U. S. Weather Bureau at Pierre further confirms the above conclusion as to the doubtful character of the 1893 gage records and the unprecedented character of the low water of 1919. The observer writes, under date of December 8, 1919:

"In regard to the extremely low readings recorded during the latter part of 1893 I wish to state that they may be ignored or at least discounted to a large extent. On July 25, 1894, I found the following note 'Gage found displaced by inspector.' There was a change of 0.6 feet made on that date to make the record accurate, i. e. the readings prior were recorded 0.6 feet too low. How long this condition prevailed prior to July 25 the records do not indicate.

"In comparing Pierre records with those of Bismarck and Sioux City, Ia., for the later part of 1893 there is a marked departure from the usual difference between the readings at Pierre and those of both Bismarck and Sioux City. Bismarck and Sioux City readings continue comparable during that time, but the Pierre records show a marked departure. Therefore, I should place but little reliance upon the records for Pierre during 1893 after August 1. Without doubt the amount of water in the river here this fall was less than at any time that we have record of."

MINIMUM FLOW OF 1919.

In general the channel at Gages 1 and 2, during each of the years reported to have been lower than 1919 had been subject to greater discharges and consequent greater erosion, the effect of which would be to increase the flow corresponding to the recorded gage height and make the comparison of gage heights misleading.

On December 31, 1918, there remained on the higher elevations of Wyoming and Montana less than one-half the average depth of snow for the four preceding years. It amounted to 12.5 inches, loosely packed, of abnormally low water content, and equivalent to 1.31 inches of water. During the first three months of 1919, 1.58 inches of precipitation increased the storage water to 2.89 inches. That amount represents nearly the total precipitation available for 1919 water and is the latest precipitation of the winter to be melted and taken up in the flow of the river. The snowfall on the higher elevations of these two states is more abundant as a rule than on any other portion of the drainage area. In each of the other six low years an amount from 20 to 25% in excess, except in 1908 and 1906 when the same and 15% less respectively, was precipitated as the average over the entire drainage area for the months of December, January, February and March alone, to be added to whatever storage remained on November 30. The year 1919 is marked among river men and inhabitants along the river in North and South Dakota as the lowest water in their several experiences.

The following clipping was taken from the Capitol Journal at Pierre:

"Missouri at Lowest Stage."

"Drought in Montana Reflected by River through North Dakota."

"Williston, N. D., July 22. The Missouri River is at the lowest stage that it has been during the 28 years of the Local Weather Bureau history. It is rated now at 1.3 feet below zero, which is 31 feet below the high water mark. Captain Bailey, who has operated on the Missouri for 55 years, says the stream is the lowest it has been in that period. The drouth in Montana is responsible."

The tenor of the Williston weather bureau record, and the opinions of men familiar with the upper Missouri River, are therefore adverse to the conclusions that might be drawn concerning the low water flow at Pierre as evidenced by the gage readings only, and careful consideration of the data at hand leads us to conclude that it is the lowest of the autumn or summer discharges of which there is record. It is also concluded that the annual minimum flow will occur during the winter in the normal year when the discharge of the stream suffers a gradual decrease from the final freezing to the opening of the river. The numerical value of the winter flow is important to this investigation because it represents probably the greatest duration of low flow occurring during the entire year, as well as the least in amount. The winter flow under ice was measured on February 11, 1920, and the discharge found to be 5,800 second feet, the lowest flow of which we have record for the past year.

In previous years there is no information available in regard to stage or discharge in the frozen season. The stage is known to fluctuate only slightly, but observation of the river throughout the past year and measurement of its discharge on February 11 of this year reveal reductions in the actual discharge that are not accompanied by any outward indications. The discharge at Pierre (5,800 second feet) was carried in two channels under the bridge and the large reduction in the cross-sectional area of the channel compared with that for open water at similar stage was

the conspicuous feature of the flow under ice. The clear water way beneath the 22 inches of ice represented a gage height of 0.9 foot. The open water discharge at that stage was found earlier in the fall to be 10,000 second feet. The apparent reduction in flow of 42 percent for ice conditions is, however, largely channel change, which is the one characteristic phenomenon of low water variation in the discharge of the Missouri River.

At the Rainbow power house of the Montana Power Company at Great Falls, the observed discharge of the Missouri was 2,440 second feet and the lowest that has ever been recorded at Great Falls.

There are available considerable data of a more general and inexact nature to the effect that the water of this particular year is the minimum, at least since 1892.

The minimum open water discharge of the Missouri at Pierre was experienced in September and again in November of 1919. The amount of this discharge was 6,000 cubic feet per second.

The year 1919 represents unusual hydrological conditions throughout and our conclusions in regard to the probable low water that may be expected on the Missouri at Pierre are predicated upon a study of these conditions in comparison with those of other years, and can best be given subsequent to the discussion of the most pertinent of the hydrological features.

STUDY OF LOW WATER FLOW BY A. H. HORTON.

Information concerning the extreme or even normal discharges of the Missouri River is meager, and a study of the low water flow by A. H. Horton of the United States Geological Survey is one of moment to the present investigation. His study was based on Seddon's Monograph, previously referred to, and his conclusions in regard to the extreme low water flows of the river at St. Charles, Mo., are derived from that work.

A consideration of Mr. Horton's conclusions is important in order to reconcile his estimates of a low water flow of 3,620 cubic feet per second at St. Charles, Missouri, with our measured minimum of 5,800 second feet at Pierre when the drainage area is less than one-half of that above St. Charles.

In regard to the basis of Mr. Horton's estimate we note:

1. The addition of 6.8 feet to a rating curve taken from Seddon's hydrograph closely approximates the "Standard Curve" of 1879 for St. Charles. (See Figure 24).
2. That since Mr. Horton obtained his rating table by adding 6.8 feet to Seddon's gage heights, Mr. Horton's curve is comparable with the Standard Curve.
3. That, below 6.8 feet, the zero of Seddon's hydrograph, Horton's table and the Standard Table compare as shown in Table 15.
4. That Seddon's hydrograph is plotted in uniform increments of discharge, not stage, and that his scale of corresponding gage height is necessarily a variable increment and, further, is not given for discharges less than 30,000 second feet.

Therefore, in the consideration of Mr. Seddon's data alone, the stage for discharges below 30,000 second feet must be estimated. In view of this fact and of the

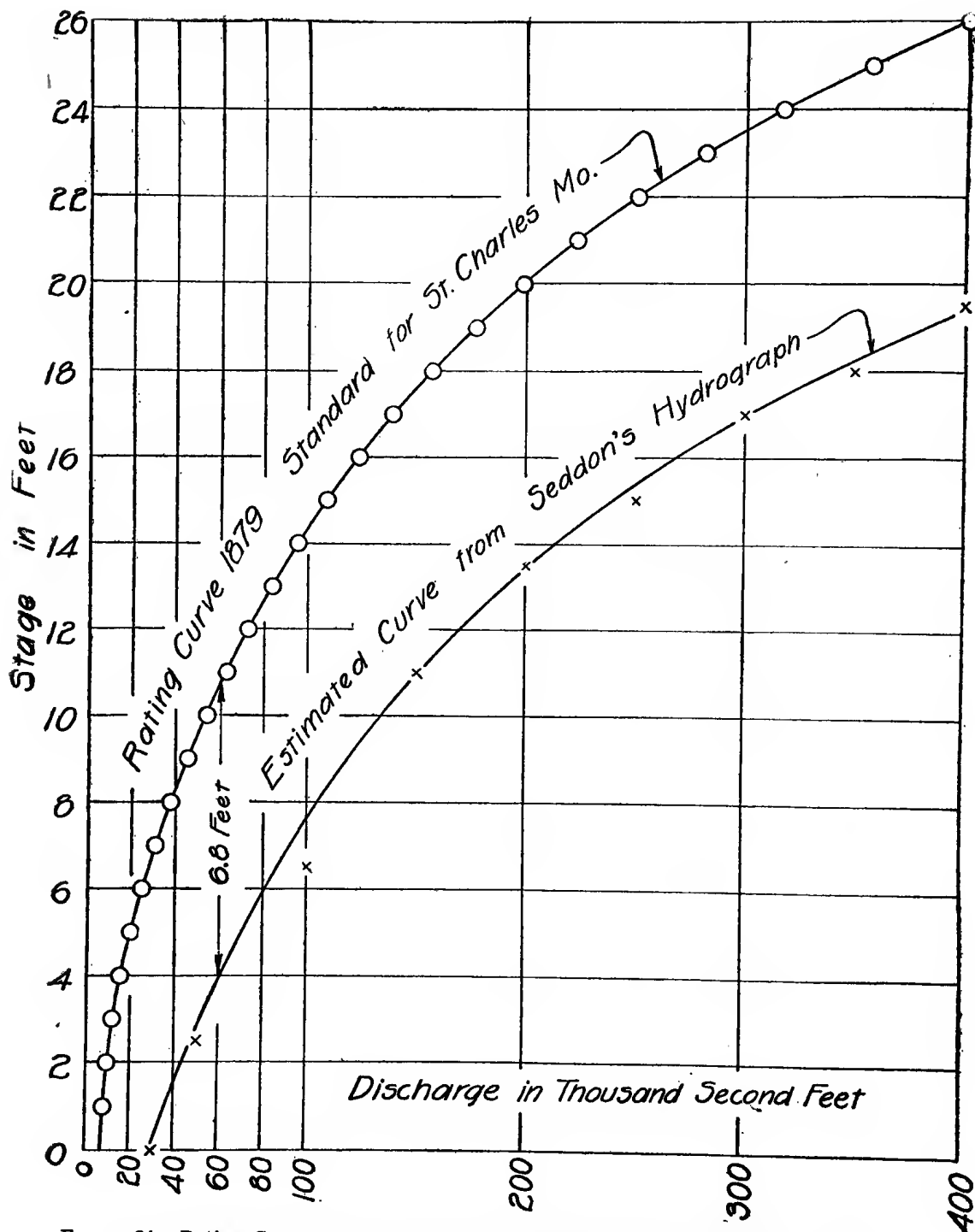


FIGURE 24. Rating Curves of Missouri River at St. Charles, Mo., from the Standard Rating table and as deduced from Seddon's published Hydrograph.

TABLE 15.

Comparison of Horton's Estimate with the Standard Discharge Table of 1870 at St. Charles, Mo.

Value of Gage at St. Charles.	General Value of Discharge, 1870.	Rating Table of A. H. Horton.
1.0 Ft.	8,400	.....
2.0	9,600	.....
3.0	12,000	1,450
4.0	15,500	8,800
5.0	20,000	16,600
6.0	25,400	24,400

variability of the scale of stages we conclude that there are probabilities of error in Mr. Horton's study too great to warrant an entire disregard of the values of the standard rating table of 1879. Considering the values given by this table, we find nothing in the minimum discharges for the two years in question that is not compatible with the minimum discharges that we have determined for the river at Pierre.

RAINFALL.

Of the hydrological factors that modify or control stream flow, precipitation is most closely related, yet the manner of distribution and other factors are so complicated as to render accurate calculations impossible. Stream flow depends wholly

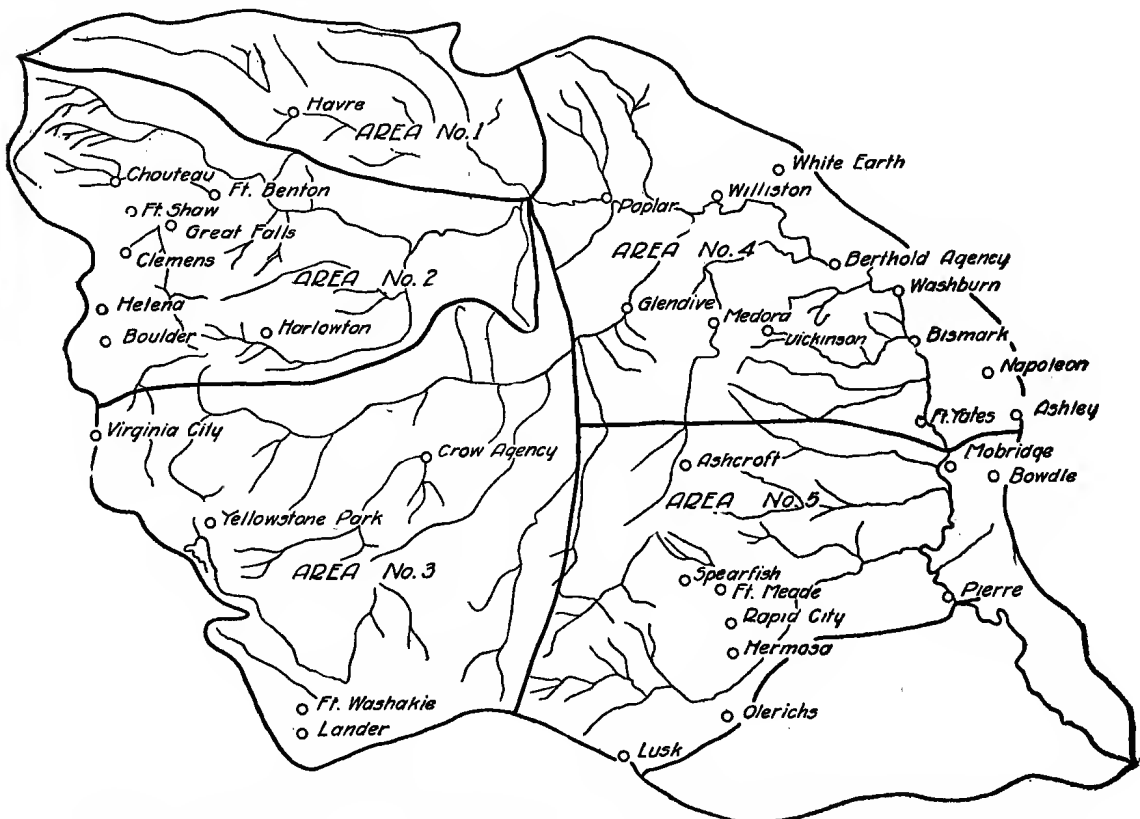


FIGURE 25. Drainage Areas of the Missouri River above the mouth of the Niobrara River.

upon precipitation, and if both are considered over a period of time sufficiently long, a fairly comprehensive relation can be established between the two. Thus, abnormal seasonal or annual stream flow can be traced as a rule to similar conditions of rainfall.

In considering the rainfall data during the period of gage record at Pierre, from 1892 to 1919 inclusive, the total monthly amounts at stations on the drainage areas above Pierre and above Mobridge are weighted and averaged over each area according to the following scheme:

Total drainage area above Pierre, 243,600 square miles, is divided into five areas:

Rainfall Stations.	
Area 1. 26,700 sq. mi.	Havre.
Area 2. 45,700 sq. mi.	Chouteau, Ft. Shaw, Clemens, Helena, Boulder, Ft. Benton, Great Falls, Harlowton.
Area 3. 64,000 sq. mi.	Virginia City, Yellowstone Park, Ft. Washakie, Lander, Crow Agency.
Area 4. 70,200 sq. mi.	Poplar, Glendive, Williston, White Earth, Medora, Dickinson, Berthold Agency, Washburn, Bismarck, Napoleon, Ft. Yates, Ashley.
Area 5. 37,000 sq. mi.	Ashcroft, Spearfish, Ft. Meade, Rapid City, Hermosa, Oelrichs, Lusk, Bowdle, Pierre.

The total monthly precipitation on each area of the five is taken as the average of the total monthly precipitation at the stations on that area, and is entered into the total for the drainage area considered in its proportionate relation to the size of the entire area considered.

Figure 26 shows graphically the results obtained. The annual values for each year for comparison with the annual amount of the stream flow are made up of twelve monthly values, commencing with November of the preceding year, and the season values used are *winter*, including November, December, January and February, and *summer*, including the remaining eight months. From the hydrological features of the drainage area, the above arrangement of annual and seasonal precipitations it is assumed will correspond more closely to the runoff conditions. The winter precipitation on the drainage area is known to supply the June rise and the major portion of the summer streamflow, and that on the higher elevations, is the latest to be received as runoff and constitutes, together with local ground storage, the major portion of the fall and early winter flow. The more abundant summer precipitation is largely consumed by evaporation and plant life; the autumn rainfall is taken up in ground saturation, though a portion of both does in some degree affect the volume of the summer and fall runoff. As the soil of the drainage area is broken

TABLE 16.

*Seasonal and Annual Precipitation from the Weighted Mean Monthly Values
over the Drainage Area above Pierre, S. D.*

Year	Winter	Summer	Total Annual
1892	3.08	14.13	17.24
1893	3.68	9.97	13.65
1894	3.05	12.69	15.74
1895	2.76	11.34	14.10
1896	3.04	13.68	16.72
1897	3.41	10.88	14.29
1898	2.66	13.86	16.52
1899	2.66	13.32	15.98
1900	2.05	12.00	14.05
1901	2.06	12.65	14.71
1902	2.55	11.74	14.29
1903	2.26	13.29	15.55
1904	2.73	10.70	13.43
1905	1.59	13.02	14.61
1906	2.24	14.99	17.23
1907	3.55	13.36	16.91
1908	1.76	15.10	16.86
1909	2.39	14.10	16.49
1910	3.37	10.00	13.37
1911	3.00	10.56	13.56
1912	2.59	15.54	18.03
1913	2.21	12.09	13.30
1914	1.82	13.61	15.43
1915	1.62	17.05	18.67
1916	2.71	14.27	16.98
1917	2.93	9.99	12.92
1918	3.05	11.38	14.43
1919	2.03	9.41	11.44
Average	2.60	12.67	15.20

up for cultivation, and the extent of agricultural development increases from year to year, the proportion of the summer and fall precipitation which has been received as ground water during the year will be somewhat altered. Its effect will be in the main to retard rather than to increase the corresponding runoff, and may effect a slight increment on the winter flow, though any such changes need hardly be considered as likely to effect a material change in flow.

From Table 15 and Fig. 26 it is seen that the precipitation for 1919 is the least of any of the years considered; that the two years 1918 and 1919 are by far the lowest

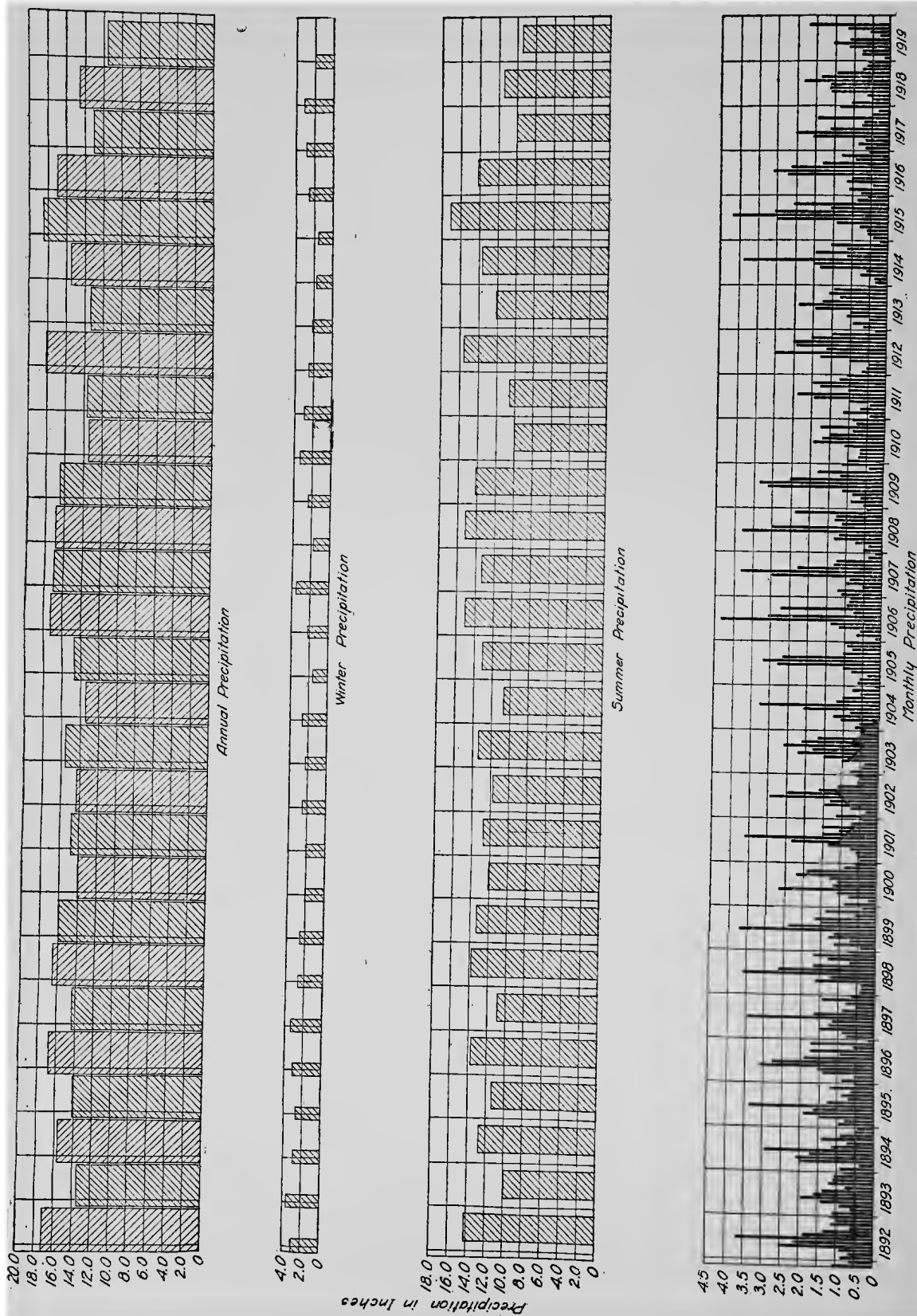


FIGURE 26. Annual, Seasonal and Monthly precipitation on the Drainage Area of the Missouri River above Pierre.

two successive years that may be found in the same period; that 1918 was preceded by a year of rainfall in 1917 nearly as low as 1919; and that the precipitation in the fall is abnormally large and considerably larger than the precipitation during any other season of 1919.

Our conclusion, previously stated, to the effect that the 6,000 second feet discharge at Pierre in the fall of 1919 was the minimum that had occurred in the season of open water within the period from 1892 to 1919 inclusive, is confirmed by above results. The three years 1917, 1918, and 1919, are the three lowest successive years, and the low water bed of 1919 was evidently not subjected to serious erosion in the four years preceding and this condition therefore favors an abnormally low discharge with a probable reduced area of channel.

With the freezing of the river the winter flow of 1919 started with abnormally low water. The unusual and early snowfall of October and November was followed by warmer weather which undoubtedly released greater quantities of water to the stream flow than is usual. When the discharge was measured on February 11, 1920, a discharge of 5,800 second feet, nearly as great as the minimum open water flow, was found.

In the normal year the stream flow would probably decrease after the freezing of the river and would not be replenished until the opening of the river in the spring. At the beginning of winter the discharge would in general be considerably in excess of the fall flow of 1919, so that it is doubtful that in the year of normal hydrological conditions, a less amount of minimum water would be experienced in the winter than has been experienced in the winter or throughout the decidedly abnormal year of 1919.

Our conclusions, therefore, in regard to the flow of the river at Pierre are as follows:

1. The least flow that has been experienced since 1892 is represented by the observed minimum discharge of 1919, 6,000 second feet in the fall and 5,800 second feet in the winter.

2. That 5,800 or 6,000 second feet is the minimum, a recurrence of which probably would not be more frequent than once in 25 years.

3. That while a flow as low as 5,000 second feet might occur once in 50 years, both the amount of such discharge and the frequency of its occurrence are purely assumptions, and in our judgment a lesser minimum than that of 1919 would be so infrequent in occurrence that it is not to be considered as modifying water power design which must however properly recognize the minimum of the past year.

LOW WATER AT MOBRIDGE.

During the summer of 1919, three gagings of the river at Mobridge were made at low water, from the Chicago, Milwaukee and St. Paul Railway bridge, two miles north of the town of Mobridge and about two miles below the site of the proposed Mobridge development. The record of gage heights at the bridge has been main-

tained by the railroad since 1911, and indicates that the lowest stage since that year, ($-0'-6''$), occurred in September and November of 1919. The rating curve shows a discharge of 4,200 cubic feet per second corresponding to that minimum gage, or 0.7 of the low water discharge that was experienced at Pierre in September and November.

The drainage area above Mobridge is 206,600 square miles and bears the ratio 0.855 to the drainage area above Pierre. The average monthly precipitation for 28 years on the drainage area above Mobridge is 0.820 of that above Pierre. It is significant that the product of the two ratios, which indicates the theoretical runoff conditions is 0.7 and equal to the ratio of the actual, observed discharges. On the basis of that ratio, the measured winter discharge at Pierre, 5,800 second feet, corresponds to 4,100 second feet at Mobridge.

APPENDIX IV.

ESTIMATES OF COST.

Our detailed estimates of the costs of development as proposed at the Mobridge site are given in the following tables which include also more approximate estimates of similar developments at the Mulehead and Medicine Butte sites. The quantities have been estimated from preliminary outline plans of the installation suggested and on lines that we have considered the most desirable under the physical and hydraulic conditions that obtain. The estimates for the transmission system are based on duplicate trunk lines from Mobridge to Aberdeen with a single loop line passing from Aberdeen to Redfield, Huron, Mitchell, Tripp, Yankton, Sioux Falls, Madison, Brookings, Watertown, Webster and return to Aberdeen, as shown on the map, Figure 2, page 15.

The secondary lines suggested for initial development the costs of which are included in the estimate, are shown on the map, Figure 3. It is obvious that the final design of the hydro-electric plant and such changes as may be desirable in the transmission lines may change our estimated quantities somewhat, but we believe that our preliminary plans represent a practical layout of the power station and the transmission system. The unit prices we have used have been taken from tentative quotations which have been obtained from various manufacturers for machinery and equipment based on our plans for this development, including prices on the hydraulic and electric machinery and equipment. Other prices used are the current prices of construction material and actual prices paid on contracts for similar material, machinery and equipment for other projects which we have installed or for which we have been preparing plans. Our estimates of cost have in all cases included liberal unit prices for labor, material and machinery. We have also provided a liberal contingency fund and have included an estimate of one million dollars for interest during construction. Many of these items may be changed if the construction is delayed for some time, and will also depend somewhat on the manner in which the work of construction is let and the basis on which the work is done.

An examination of our estimates may lead those unfamiliar with the contingencies of hydraulic construction to conclude that the unit prices used are unduly large even under existing conditions. We have endeavored to make a sufficiently liberal estimate so that by good management and with reasonably favorable conditions the actual cost will not exceed the estimates we have made. Our personal experience in the design and construction of hydraulic plants has taught us that there are many

DETAILED ESTIMATE OF COST OF TRANSMISSION SYSTEM.

TABLE 17.

110,000 Volt Transmission Line.

	Each	Per Mile.
Wood Poles—8" Top 40' BB butt treated.....28 @ \$20.00.....		\$560.00
Cross Arms—Two 6"—8# Channels 5950 @ .08.....		476.00
Bayonets 72" 28 @ 1.95.....		54.60
Insulators 294 @ 2.60.....		746.40
Cable Clamps 42 @ 2.00.....		84.00
Arcing Rods 42 pair @ .45.....		18.90
Saddle for aluminum cable protection.....42 @ .10.....		4.20
Belcher Clamps "J" type.....28 @ .11.....		3.08
Three bolts 56 @ .10.....		5.60
Ground wire—¼" D. G. Siemens Martin....10700 ft. @ 1.75 per 100.....		187.25
No. 00000 Aluminum cable, steel reinforced....5380# @ .30.....		1,614.00
Digging holes 28 @ 1.50.....		42.00
Distributing poles 28 @ 1.00.....		28.00
Distributing wires 1½ tons @ 8.00.....		12.00
Distributing insulators 294 @ .05.....		14.70
Distributing cross arms and hardware.....		15.00
Setting poles and assembling 14 @ 15.00.....		210.00
Stringing 3 cables and 2 ground wires.....5 @ 60.00.....		300.00
Extra for strains, guys, and extra labor 10%		\$4,374.73
		\$4,812.20
Right of way		160.00
		\$4,972.20
Total per mile of single trunk line.....		\$4,972.20
Duplicate Trunk Line		\$9,944.40
<i>Transmission Loop.</i> Estimated on basis of a single line of No. 00 steel reinforced aluminum cable. This estimated cost would be the same as that for the single trunk line above modified for the different size of cable and extra items for strain insulators, guys, labor, etc.		
Total per mile for main items.....		\$3,646.73
Strains, guys extra labor.....		911.67
Right of way		200.00
Total per mile of loop line.....		\$4,758.40

TABLE 18.

Secondary Lines.

		Each	Per Mile.
Wood poles 8" top 35' BB butt treated.....	26 @	\$15.00.....	\$390.00
Cross arms, steel	26 @	4.00.....	104.00
Insulators and pins	78 @	3.50.....	273.00
Tie wire	26 @	1.10.....	29.00
Bayonets	26 @	1.50.....	39.00
Belcher Clamps	26 @	.11.....	2.86
Bolts	78 @	.10.....	7.80
Ground wire $\frac{1}{8}$ " D. G. Siemens Martin.....	5400' @	1.50 per 100'....	81.00
#0 Aluminum Cable, Steel reinforced.....	2300* @	.30.....	690.00
Digging holes	26 @	1.50.....	39.00
Distributing materials			35.00
Stringing 3 cables and 1 ground wire.....	4 @	60.00.....	240.00
Erecting poles and cross arms	26 @	7.00.....	182.00
			\$2,112.66
Extra for strains, guys and labor 20%			422.44
			\$2,535.10
Right of way			250.00
			\$2,785.10

Summary of Line Costs.

Trunk line—Mobridge to Aberdeen.....	100 mi. @	\$9,944.40.....	\$994,440.00
Loop line—Aberdeen to Sioux Falls.....	464 mi. @	4,758.40.....	2,207,900.00
Secondary lines	600 mi. @	2,785.10.....	1,647,060.00
			\$4,849,400.00

Summary of Substation Costs.

11 Primary substations	33,500 KW @	\$27.00.....	\$904,500.00
Secondary substations	5,000 KW @	20.00.....	100,000.00
			\$1,004,500.00
Total			\$5,853,900.00
Engineering, Contingencies and Interest during construction			1,190,100.00
			\$7,044,000.00

TABLE 19.—Continued.
Detailed Estimate of Cost of Development with Thirty Foot Head.

Element	Material	Unit	Moblridge			Mulehead			Medicine Butte		
			Quantity	price Unit	Cost Estimated	Quantity	Unit price	Estimated Cost	Quantity	Unit price	Estimated Cost
<i>Lock</i>											
Gates.....	Steel.....	Sq. Ft.....	5,810	\$15.00	\$87,200	5,810	*	\$87,200	5,810	*	\$87,200
Lock.....	Concrete.....	Cu. Yd.....	41,600	15.00	625,000	41,600		625,000	41,600		625,000
Piling.....	Timber, round	Lin. Ft.....	198,000	0.60	118,800	198,000		118,800	268,000		161,000
Steel sheeting	12" x 42½"	Ton (driv'n)	935	100.00	93,500	935		93,500	935		93,500
Excavation.....	Sand, gravel	Cu. Yd.....	4,130	1.00	4,130	4,130		4,130	70,500		70,500
		Total	Total		\$928,630	Total		\$928,630	Total		\$1,087,200
<i>Abutments</i>											
Abutments.....	Concrete.....	Cu. Yd.....	11,435	15.00	\$171,660	11,435		\$171,660	11,435		\$171,660
Steel sheeting	12" x 42½"	Ton (driv'n)	183	100.00	18,300	203		20,300	203		20,300
Piling.....	Timber, round	Lin. Ft.....	7,670	0.60	4,600	8,000		4,800	8,000		4,800
Excavation.....	Sand, gravel, shale	Cu. Yd.....	10,000	1.00	10,000	9,800	2.00	19,600	10,000	1.00	10,000
		Total	Total		\$204,560	Total		\$216,360	Total		\$206,760
<i>Railway Spur</i>											
Track and materials	Rails, ties, tie plates, bal- last, etc.	Foot Each Total	15,125 7	1.50 280.00	\$22,700 1,960				31,700	*	\$47,500
Switches.....		do			5,000				7		1,960
Grading.....		do			3,000						80,000
Track laying.....	Piling, timber	Foot	500	10.00	5,000						18,000
Trestle.....	12" x 42½"	Ton (driv'n)	100	100.00	10,000				150		14,000
Steel sheeting.....		Total	Total		\$48,660	Total		\$300,000	Total		\$116,460
<i>Embankment</i>											
Core wall.....	Concrete.....	Cu. Yd.....	7,410	18.00	\$133,500	3,970	*	\$71,500	2,035	*	\$36,600
Excavation.....	Sand, gravel	do	4,550	1.00	4,550	4,000		4,000	3,500		3,500
Steel sheeting.....	12" x 42½"	Ton (driv'n)	2,738	100.00	273,720	1,100		110,000	1,540		154,000
Net fill.....	Sand, gravel	Cu. Yd.....	700,980	0.60	420,000	310,000		186,000	165,300		99,180
Revetment.....	Boulders	Square	1,840	10.00	18,400	4,030		40,300	3,960		39,600
		Total	Total		\$850,170	Total		\$411,800	Total		\$332,880
<i>Flowage</i>											
Cofferdam and Pumping.....	River Land	Acre.....	20,000	25.00	\$500,000			\$1,000,000			\$1,000,000
					\$300,000			\$600,000			\$600,000
Total.....					\$7,432,992			\$10,010,712			\$10,924,252
<i>Engineering and Contingencies and interest during con- struction</i>											
					1,670,008			\$2,250,288			\$2,460,748
Total cost.....					\$9,103,000			\$12,261,000			\$13,385,000

* See Mobilridge unit prices.

contingencies, which may arise in such construction, that we cannot foresee or provide for except by the use of liberal unit prices. In an estimate of this kind there are many items and expenses which cannot easily be tabulated when only outline plans are used, but which must be covered by a liberal estimate. It should also be noted that the problem of making an estimate at this time when prices are rapidly fluctuating and may increase or decrease materially in the near future, is a serious undertaking and cannot be safely done except by the use of liberal unit cost estimates. It is obvious that a continued rise in the cost of labor, material and machinery in the next year or so may render even the liberal prices we have used inadequate for the construction of the proposed development. At the present time prices are in most cases at least 67 percent. above the prices of 1915, and in some cases they have more than doubled. It is also obvious that whenever the country returns to a sound business basis, a reduction in present prices is to be expected. We believe, however, that nothing short of a serious financial panic will return prices to their pre-war basis. The rise in the cost of labor will, at least to a considerable extent, be permanent and a consequent rise in the cost of material, machinery and other equipment into which the cost of labor enters to a large degree will necessarily be greater than those which obtained under pre-war conditions, although it is hardly probable that they will remain at the present inflated values.

While any estimate of the decrease in cost which will accompany the return of the country to a stable business condition must be uncertain, we confidently expect an ultimate decrease of about 25 percent. in the present costs, though when this return will occur is uncertain. It can hardly be expected for at least one or two years. All these matters have been carefully considered in making our estimates which we believe are adequate to cover actual costs at the present time.

APPENDIX V.

TRANSMISSION SYSTEM.

The transmission system which we have suggested would serve the existing market equally well from the Mobridge, Mulehead or Medicine Butte sites, each tentatively considered as a first development. The proposed plan to develop the Mobridge site first and later to develop the Mulehead site to supply the future market with power in excess of the capacity of the first development, includes transmission from both plants over the same loop of 110,000 volt line.

When the output from the Mulehead plant is delivered to the system at the southern end of the loop, the distribution losses will at first decrease. When the amount of power delivered with two plants in operation is the same as it would be with one alone, the normal power loss in the loop will be reduced with power sources at both ends. The increase in power demand over the system, however, operates to maintain the loss over the original line practically the same for one, two, or three plants. The possibility of interruption to the continuity of service would be reduced as the number of plants increase and attendant loss of undelivered power is greatly reduced.

In the subsequent comparison of the size of conductors to be used in the loop line, an economy is shown in the installation of No. 00 aluminum cable for the transmission of power in quantity up to the full capacity of the Mobridge development and of No. 000 cable for the transmission of greater amounts.

The cost of substation equipment on the primary line of 110,000 volts limits the economical transformation to the final voltage of 2,300 for distribution to a load of 500 KW. Eleven such stations have been selected and it is proposed to supply those communities directly from the primary lines and to extend secondary systems from those points to serve the smaller loads.

The substations and the data pertaining to the proposed transmission are as given in Table 20.

With a primary 110,000 volt line as a main arterial feeder located about the center of the power market, east of the Missouri River, the greatest number can be served with the least expenditure. The mining region of the Black Hills has its own hydro-electric power for the present uses but ultimately as the country west of the Missouri River is developed, additional powers at Medicine Butte, Reynolds Creek, etc. may be developed and connected to the system outlined above and also to lines extended to the west as needed.

TABLE 20.

Location of Substations, Proposed Capacities, and Distances Apart.

Mobridge Site.

Location.	Voltages from to		Proposed Capacity Kilowatts	Present Installation K. W. Kilowatts	Line between Stations Miles
Aberdeen	110,000	{ 2,300 33,000	5,000	2,230	100
Webster	"	"	500	262	50
Watertown	"	"	3,000	915	36
Brookings	"	"	1,000	438	50
Madison	"	"	3,000	600	32
Sioux Falls	"	"	10,000	8,426	27
Yankton	"	"	2,000	485	58
Tripp	"	"	1,500	600	38
Mitchell	"	"	3,000	1,115	34
Huron	"	"	3,000	996	50
Redfield	"	"	1,500	685	40
Aberdeen .....	"	"	....	....	40
Total			33,500	16,725	565

The primary line which we have suggested consists of a duplicate line from Mobridge to Aberdeen, and from each hydro-electric plant as developed, to the loop feeder system. The line from Aberdeen to Yankton via Watertown and Sioux Falls, likewise from Aberdeen to Yankton via Huron and Mitchell may well be a single three-phase circuit. The length of duplicate line from Mobridge site to the loop line is about 100 miles and from the Mulehead Site, about 50 miles. The single circuit loop line is about 464 miles in length. This loop line serves the purpose of a duplicate line due to the fact it traverses different paths and hence the chance of both single lines going down in the same storm are not so great as with a duplicate line over one path. The length of line and the quantity of power involved necessitates a careful study of the voltage, size of cable, type of line supports, insulators, etc. for present and future developments.

MAIN LINE FROM MOBRIDGE TO ABERDEEN.

Two trunk lines must be used for two reasons:

First: To decrease the chance that the failure of a support, or of a string of insulators, or the breaking of a conductor will result in a serious interruption to the supply of power. The trunk lines are divided into "sections" and with duplicate trunks the section of the line "in trouble" can be disconnected from the system until repairs are made, and the supply of power continued over the other line and the good sections of the damaged line.

Second: It is not feasible to maintain the necessary constancy of voltage from one end of this extended system to the other if all the power is supplied over a single trunk, because the "reactance" of a single trunk is too great. The only method of appreciably reducing the trouble is to use two lines in parallel, which reduces the reactance of the system to substantially one-half that of a single trunk line.

33,000 VOLT DISTRIBUTING LINES.

It is not economical to supply small towns and villages (communities or customers having a peak load of less than 500 kilowatts) directly from the 110,000 volt trunks because of the high cost per kilowatt of capacity of the 110,000 volt switching and transforming equipments which would be required. The small customers must, therefore, be supplied by lower voltage three-phase transmission lines or in some cases single phase lines, which radiate from a few main transforming stations located at load centers along the 110,000 volt transmission lines. The voltages suitable for this distributing system are 33,000 and 13,200, depending on the extent of the district to be supplied from the load center.

Accordingly, at such load centers as Aberdeen, Redfield, Huron, Mitchell, Tripp, Yankton, Sioux Falls, Madison, Brookings, Watertown, and Webster, the power from the 110,000 volt trunks should be transformed to a voltage required by the existing distributing systems of the individual community, namely 2,200, 4,000, or 6,600 volts, and also to 33,000 or 13,200 volts for the supply of the towns in the surrounding territory. At each of these small towns, the power from the 33,000 volt distributing lines should again be transformed to a voltage of 2,200 or 4,000 for the supply of the local distributing system. The length of 33,000 and 13,200 volt line necessary to supply the towns indicated on Figure 3 is 600 miles.

SUBSTATIONS.

In our estimates we have provided for outdoor substations of a modern type. The substations at Aberdeen, Huron, and Tripp provide for two three-phase 110,000 volt incoming lines from three proposed generating plants. At Aberdeen one 110,000 volt line leads to Webster and one to Redfield; likewise at Tripp, one to Mitchell and one to Yankton. The Huron station provides for one line to Redfield, one to Mitchell and one to Brookings. The Brookings station provides for one line to Huron, one to Madison and one to Watertown. The Redfield, Mitchell, Yankton, Sioux Falls, Madison, Watertown and Webster stations provide for one incoming and one outgoing 110,000 volt line. All of the substations and the generating stations have provision for 2,300 volt, 13,200 volt or 33,000 volt lines and in most cases provision for all of these voltages has been made. The secondary substations are also of the outdoor type of modern design.

DETERMINATION OF THE ECONOMICAL TRANSMISSION VOLTAGE.

The following considerations lead to the selection of 110,000 volts rather than the next higher standard voltage (namely 150,000 volts) as the transmission voltage.

With a peak load of 36,000 K. W. supplied at 110,000 volts over the two trunks, the power component of the current per wire in the trunks from Mobridge to Aberdeen is 94.5 amperes. At present prices, the economical size of wire to transmit this current is somewhat larger than 5/0 steel reinforced aluminum cable (equivalent to 3/0 copper). If the 100 miles of duplicate trunk from Mobridge to Aberdeen were strung with 5/0 steel reinforced aluminum and the loop with 3/0 aluminum cable (equivalent to 0 copper), the cost of wire for the 110,000 volt primary lines would be:—

200 miles 5/0 aluminum (equivalent 3/0 copper) at	\$1,635 = \$327,000
464 miles 3/0 aluminum (1/0 copper) at	1,100 = 510,000

Total	\$837,000
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If the duplicate trunk line from Mobridge to Aberdeen were strung with 5/0 and the loop line 2/0 steel reinforced aluminum cable the cost of wire for 110,000 volt primary lines would be

200 miles 5/0 aluminum (equivalent 3/0 copper) at	\$1,635 = \$327,000
464 miles 2/0 aluminum (equivalent No. 1 copper) at	869 = 402,500

Total	\$739,500
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CALCULATIONS RELATING TO THE ECONOMICAL SIZE OF CONDUCTOR.

1. *Interest and Depreciation Charges on the Conductors.*

The bonds which would be issued to finance the construction of the line are assumed to bear 5 percent. interest.

An annual charge of one percent of the cost of the conductors to cover depreciation is based upon the following assumptions: (a) conductors are to be replaced after 25 years; (b) the net amount realized on steel reinforced aluminum cable after 25 years is taken as 50 percent. of the first cost; (c) the sinking fund is assumed to earn five percent. interest.

2. *Annual Charges for Interest, Depreciation, and Lost Power.*

The economical size of conductor is that for which the sum of the annual charges for interest and depreciation plus the cost of the power expended (lost) in the resistance of the conductor is a minimum. The following calculation relates to the economical size of conductor for the 100 miles of duplicate line in the parallel from Mobridge to Aberdeen.

When the station is delivering 36,000 KW to the trunk lines, the current along the trunk line from Mobridge to Aberdeen will be about 100 amperes per wire per trunk at the time of peak load.

The following table shows the annual charges computed in like manner for 6/0, 5/0, and 3/0 steel reinforced aluminum cable.

TABLE 21.

Annual Charges Per Mile of Three-Phase Line.

Size of Cable.	6/0	5/0	4/0	3/0
Interest and depreciation	\$151	\$98	\$83	\$66
Cost of lost power	100	125	166	199
Total	\$251	\$223	\$249	\$285
Total annual charges for the 200 miles of line in the parallel	\$50200	\$44600	\$49800	\$57000

This comparison indicates that the 5/0 cable is the most economical conductor for the 100 miles of duplicate line in the parallel from Mobridge to Aberdeen under the assumption stated in the calculations, and after the station is fully loaded.

In the loop beyond Aberdeen, the current will taper off toward the far end in a manner which will depend upon the distribution of the load. It will be economical to use a cable smaller than 5/0 steel reinforced aluminum in the loop, possibly a 3/0 cable.

COMPARISON OF 150,000 AND 110,000 VOLT LINES.

If a transmission voltage of 150,000 were used, the load current would be 73.3 percent. as great and the economical size wire would weigh 73.3 percent. as much as the wire for the 110,000 volt line, or the cost of the wire for the 150,000 volt line would be \$615,000. But the insulators for the 150,000 volt line will cost \$183,600 more than for the 110,000 volt line, and the 150,000 volt transforming, switching, and protective equipment is estimated to cost \$144,000 more than the 110,000 volt equipment. The sum of these two extra investment items plus the \$615,000 for the 150,000 volt wire is \$942,600, or slightly greater than the cost of the 110,000 volt conductors. This indicates that for the conditions which will obtain when the system is fully loaded (10 years hence) the annual charges for the 110,000 volt system will not be much greater than for the 150,000 volt system.

The above comparison has been carried through on the assumption that the power losses due to the formation of a corona discharge around the wires will not preclude the use of the most economical size of wire for each transmission voltage. Now the smallest wire which may be used without corona losses at 110,000 volts is 2/0 stranded steel reinforced aluminum cable. (No. 1 copper equivalent). Therefore at 110,000 the most economical size of wire may be used.

On the other hand the smallest cable which may be used without corona losses at 150,000 volts is 266,800 circular miles steel reinforced aluminum cable (equivalent to 3/0 copper). The 664 miles of three cables of this size will cost \$1,080,000 making the sum of costs of the 150,000 volt wire with the additional insulator and transformer costs will be as given in Table 22.

TABLE 22.

<i>Cost of 150,000 Volt Wire and Additional Insulator and Transformer Costs.</i>	
150,000 volt wire	\$1,080,000
Additional cost of insulators	183,600
Additional cost of transformers etc.....	144,000
Total	\$1,407,600

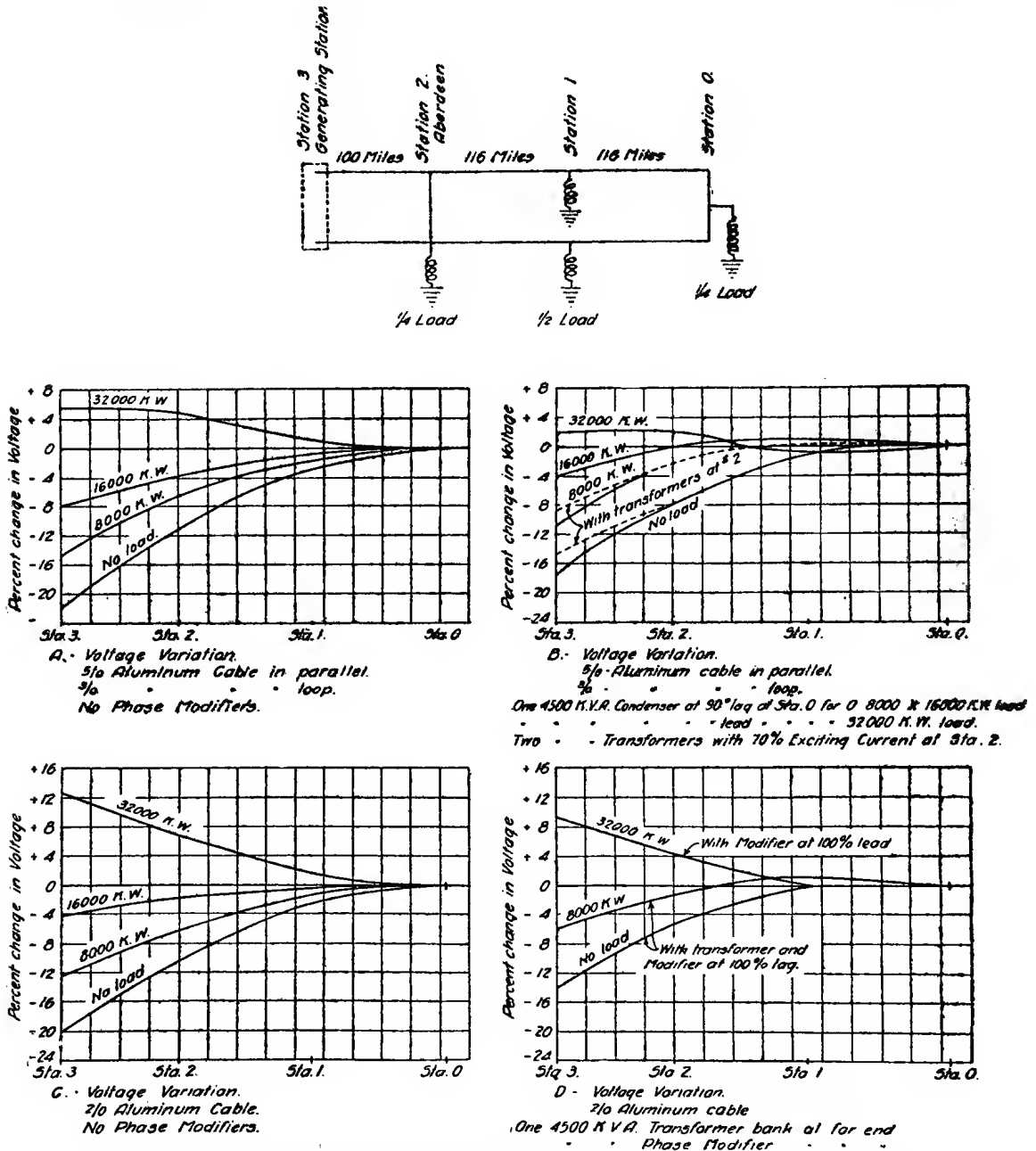


FIGURE 27. Diagrammatic Representation of the Voltage Regulation of the Proposed Primary Transmission System at Various Loads.

That is, the 150,000 volt system suitable for the full development of the Mobridge site would cost \$570,600 or \$668,100 more than the 110,000 system depending on whether 3/0 or 2/0 steel reinforced aluminum cable is used on the 110,000 volt line.

A consideration of even greater weight in favor of the selection of 110,000 volts is as follows. Until the plant at Mobridge is fully loaded the cost of developing the power necessary to supply the line losses cannot be taken as 0.7 of a cent per kilowatt hour, since the only expense incurred in providing for the lost power is the interest and depreciation on a fraction of an additional generating unit. This will amount to less than 0.1 of a cent per kilowatt hour. Under these conditions, the smallest wire which will provide for satisfactory voltage regulation is the most economical during the early years of the plant.

In the succeeding sections it is shown that the installation of 2/0 aluminum cables will provide for satisfactory voltage regulation, and that the installation and use of this size will be warranted if a period of ten years is required to develop the load before the load on the system approaches the capacity of the Mobridge plant. 664 miles of three-phase line consisting of 2/0 aluminum cable will cost \$575,000 or \$832,600 less than the corresponding initial outlay if 150,000 volts is used.

VOLTAGE REGULATION OF THE TRANSMISSION LINE.

The distance along the proposed line from Mobridge to the farthest point is 332 miles. This distance exceeds the longest straight-away transmission system now in operation, (the Big Creek-Los Angeles transmission) by 90 miles. The unusual length of the system coupled with the small load give rise to several unusual features.

The power component of the load current per wire when delivering the peak load of 36,000 K. W. over two trunks will be 94.5 amperes. The corresponding charging current per wire when delivering no load is 112 amperes. That is to say, before the unloaded lines can be connected to the station, equipment sufficient to provide a current in excess of the full load current must be installed. This large charging current flowing through the reactance of the lines would cause the voltage at the far end of the line to exceed the voltage at the generator end by 22 percent.

The percentage by which the voltage at different stations exceeds or falls below the voltage at the far end is shown by the curves C of Figure 27. Each curve is plotted for a given load delivered along the line. Thus at a load of 32,000 K. W., the voltage at the generating station must be 5.6 percent higher than the voltage at the far end, and at very light loads the generator voltage must be 22.4 percent lower than the voltage at the far end. The variation in the voltage over the line which these curves indicate cannot be permitted. To permit of maintaining the voltage of the line from the generator end to the load end reasonably constant, the method of voltage regulation by "phase control" must be resorted to. This will require the installation of two 6,000 KVA synchronous condensers or phase modifiers, probably at Sioux Falls. The large charging current of the line if allowed to get back to the generators will be very objectionable in two respects. First: The kilowatt ampere capacity of

the generators and transformers will have to be much larger than their (useful) kilowatt capacity. Second: The leading or charging current will be sufficient to excite the generators to full voltage with no field excitation. This will make it difficult to control the generator voltage.

To avoid these effects the step-up transformers of the generating station may be designed to have an exciting current of the order of 70 percent of the full load current instead of the usual 4 to 10 percent. The leading line charging current delivered by the high tension coils of these transformers furnishes the large exciting magnetomotive force needed by these transformers and thus relieves the generators and low tension coils of the necessity of supplying any current save useful or inphase current. This means that it will be necessary to install only 4 or 5 of the 10 generating units at the beginning—the other units to be installed as the load builds up.

To provide the line charging current it will be necessary to purchase at the beginning the 36,000 K. W. in transformer banks needed for the ultimate development. However, in the beginning these banks need not all be installed at the generating station. If one bank is installed at Sioux Falls and a second bank at Aberdeen a single phase modifier will be sufficient to furnish the additional lagging current needed for phase control of the voltage at light load. As the load builds up first one bank and then the second can be shifted to the generating station and an additional phase modifier installed.

CALCULATIONS RELATING TO THE VOLTAGE VARIATION.

While the manner in which the load will be distributed along the trunk lines can not be predetermined, a fair conception of the variation in voltage to be expected, and of the need of phase modifiers for controlling the voltage, can be obtained by plotting curves showing the variation in voltage along the line for the load distribution shown in Figure 27.

The load is assumed to be delivered to three substations number 0, 1, and 2 in Figure 27. One quarter of the load is assumed to be delivered to Station 2, which is 100 miles from the generating station 3. Station 2 corresponds to Aberdeen. One quarter of the load is assumed to be delivered to Station 2, which is 100 miles from the generating station, 3. Station 2 corresponds to Aberdeen. One quarter of the load is assumed to be delivered to Station 0, which is 332 miles from the generating station. One-half of the load is assumed to be delivered to Station 1, which is midway between Station 0 and Station 2.

Curves on Figure 27 have been plotted showing the percentage by which the voltage at each station exceeds or falls below the voltage of the station at the far end of the line,—Station 0. The voltage at this station has been taken as 110,000. Each contains the curves for a transmission line conductor of specified size with specified phase regulating equipment. Each individual curve is plotted for a specified load delivered along the line. The load at each station is assumed to have a power factor of 85 percent lagging.

From these curves the tentative conclusion is drawn that two 6,000 KVA synchronous condensers will be needed to maintain the necessary constancy of voltage with varying load. The best location for these synchronous condensers is to be determined after the load distribution is more definitely known.

THE ECONOMICAL SIZE OF CONDUCTOR FOR THE TRUNK LINES.

It has been shown that to make the annual charges for the cost of the power lost in the conductor plus the interest and depreciation charges on cost of the conductor a minimum 5/0 aluminum cable should be used to transmit a current of 94.5 amperes. As previously pointed out, under the conditions surrounding an hydro-electric installation and until the plant becomes fully loaded, it costs the operating company substantially nothing to supply the power lost in the conductors. Therefore as the Mobridge station will not be fully loaded for perhaps 10 years from the present time or 5 years after its completion, it may be found economical to install a small conductor which will later be replaced by the economical size for full load. Number 2/0 aluminum trunk lines from Mobridge to Aberdeen will provide satisfactory voltage regulation for some time and the question of market may favor the installation of 2/0 cable as a first development.

The respective expenditures incurred in 10 years and in 5 years in installing 5/0 and 2/0 aluminum trunks between Mobridge and Aberdeen are as follows:

TABLE 23.

Fixed Charges on 5/0 Aluminum Trunks.

First cost 100 miles duplicate line—\$327,000.

Period of Service	10 years	5 years
Interest at 5% per annum compounded.....	\$205,627	\$90,343
Depreciation 2% per annum	65,400	32,750
Total expenditures	\$271,027	\$123,093

Fixed Charges on 2/0 Aluminum Trunks.

First cost 100 miles duplicate line—\$175,000.

Period of Service	10 years	5 years
Interest at 5% per annum compounded.....	\$114,000	\$48,349
Depreciation	87,000	58,300
Labor taking down 2/0 and restringing large size .	24,000	24,000
Total expenditures	\$225,500	\$130,649

In addition to the saving which is thus shown to result from the initial installation and ultimate replacement of small conductors, a second consideration of greater weight makes such a course advisable. If the two construction programs had been shown to result in equal operating expenditures over a long period of years, it would

be imprudent to adopt at this time that building program which makes the greater immediate demand upon the world's depleted stock of materials. From a financial standpoint it may be advisable to install initially a smaller conductor because it may be possible in several years to purchase a large conductor for 60 to 70 percent. of its cost at the present high prices.

NECESSARY PRECAUTIONS TO AVOID INDUCTIVE INTERFERENCE.

In those instances in which troublesome interference has been experienced between a power line and nearby telephone lines paralleling the power line, the interference has not been due to the useful 60 cycle currents which the power line conveyed. The inductive interference has been caused by unbalanced or residual alternating currents and electric charges of a frequency much higher than 60 cycles.

The measures necessary to reduce these residual higher harmonics to unobjectionable magnitudes would be adopted at the inception of this work, because if adopted at the beginning such preventive measures add comparatively little to the cost of the project. These measures are:

First: the reduction of the residual currents to a minimum by the transposition of the 110,000 volt and 33,000 volt power lines at intervals of 2 or 4 miles (length of barrel 6 or 12 miles).

Second: The restriction of the amplitude of the harmonics in the wave form of the generators to the minimum feasible values, by suitable generator characteristics.

Third: The restriction of the magnitude of the harmonics in the exciting current of the high tension step-down transformers by proper transformer characteristics relating to the magnetic flux densities which may not be exceeded in the transformer design.

The Railroad Commission of the State of California as a result of a very extended study of inductive interference carried out by a joint committee representing all the interests concerned issued an order dated July 13, 1918, known as "General Order No. 52 in the Matter of the Construction and Operation of Power and Communication Lines for the Prevention or Mitigation of Inductive Intereference."

The measures advocated above comply with the provisions in this order relating to the construction of power lines paralleling a telephone line on the opposite side of a highway.

APPENDIX VI.

EFFECT OF SILT ON THE DEVELOPMENT OF POWER.

Our attention has been called to the question of the possible effect of the silt carried by the Missouri River upon the turbines of the power plant and upon the reservoir capacity above the dam. This matter has not been discussed in the main report because of the fact that we did not consider it of sufficient importance to require detailed consideration.

Under high heads with consequent high velocities of discharge, the presence of sand and silt sometimes produces serious erosive effects upon the buckets of turbine runners and necessitates the elimination of such material by sedimentation or the use of more highly resistant metal in the runners.

Under the lower head which will obtain on any of the Missouri River Plants which can be constructed in South Dakota, the erosive effect of silt will not prove serious, although its effect may occasion the earlier renewal of turbine runners, but we do not consider it likely that such renewals will have any important influence on maintenance costs.

As to the effect of silt in the reservoir above the dam there can be no doubt but that the construction of a dam and the resulting decrease in the velocities of the river for many miles above will produce deposition which will begin at the upper limits of the pond and extend down stream to the dam, ultimately causing a considerable fill in the pond.

It is to be noted, however, that we have given little weight to the use of storage waters for power purposes, but that the power output is estimated essentially upon the basis of the ordinary flow of the stream. The annual floods will, without doubt, keep the channels excavated to an amount sufficient to supply the limited storage necessary to supplement the ordinary deficiencies of flow. The effect of the silt in reducing the capacity of the pond is not believed to be a matter of serious consequence.

